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Scientific monographs E:41 · 2009

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The views expressed in this study are those of the authors and do not necessarily reflect the views of the Bank of Finland.

ISBN 978-952-462-498-5
ISSN-L 1798-1077
(print)

ISBN 978-952-462-499-2
ISSN 1798-1085
(online)

Multiprint Ltd
Helsinki 2009

Abstract

It is a commonly accepted fact that innovation is important for economic growth and that a well-designed patent system increases research and development investments. Patents are unfortunately a second best solution. While the benefits of the patent system are increased incentives to innovation, diffusion of new knowledge, and easier commercialization of patented innovations; the drawback of the patent system is the monopolies it creates. Therefore, the fundamental question that has interested researchers is: do the benefits of the patent system outweigh the costs? This thesis contributes to the literature that quantifies the benefits of the patent protection to the assignee after the patent is granted, ie the private value of patents. In three of the four essays here, I estimate how different patent and assignee characteristics affect the private value of Finnish patents. The private value distribution of patents is calculated using patent renewal rates and fees and advanced econometric techniques. In the fourth essay I test how a legal change in the statutory length of patents has changed the private value of patents in Finland. To do this, I use non-parametric techniques. The last essay contributes to the discussion on optimal patent design. I present two overall policy recommendations based on the essay findings. First, I find that the distribution of the private value of patents depends not only on patent characteristics but also on patent assignee characteristics. This derives from the fact that it takes time and money to learn the private value of a patent. Also, there seem to be financial imperfections that, especially for smaller firms, restrict the internalization of patent revenues. If patents are seen as a good incentive mechanism for innovation, the policy implication is that commercialisation of patented innovations should be supported. Second, I find, using the patent law change as a natural experiment, that the statutory patent length of 20 years is too long. The optimal patent length is shorter than 18 years in Finland.

Keywords: patent, private value, renewal rates, renewal fees, Finland
JEL classification codes: O34, C01

Tiivistelmä

Teknologian kehitystä pidetään yleisesti tärkeänä yksittäisenä talouskasvun selittäjänä ja hyvän patenttijärjestelmän katsotaan lisäävän tutkimus- ja kehitysinvestointeja. Patenttioikeuksien ongelma on kuitenkin se, että samalla kun nämä oikeudet kannustavat innovoimaan, lisäävät tiedon leviämistä ja helpottavat patenttialaisen tuotteen kaupallistamista, ne myös luovat monopolivoimaa, mikä taas haittaa teknologian kehityksen käyttämistä laajasti yhteiskunnassa. Immateriaalioikeuksien taloustieteessä keskeinen kysymys kuuluukin, ovatko patenttijärjestelmästä saadut hyödyt suuremmat kuin haitat. Tämä tutkimus liittyy osaltaan empiiriseen kirjallisuuteen, jossa mitataan patenttisuojan patentin omistajalle antamaa hyötyä patentin myöntämisen jälkeen eli ns. patentin arvoa. Kolmessa neljästä artikkelista tarkastellaan patentin ja sen haltijan ominaisuuksien vaikutusta suomalaisen patentin arvoon. Patentin arvon jakaumaa estimoidessa käytetään patentin uusimispäätöksiä ja vuosimaksuja sekä kehittyneitä ekonometrisiä menetelmiä. Viimeisessä artikkelissa tutkitaan ei-parametrisin menetelmin mikä vaikutus patentin arvoon oli lailla, joka pidensi patentin lakisääteisen pituuden 17 vuodesta 20 vuoteen. Tämä artikkeli liittyy osaltaan optimaalisesta patenttijärjestelmästä käytyyn keskusteluun. Tutkimuksen tuloksista voidaan politiikkakeskustelun kannalta nostaa esiin kaksi keskeistä tulemaa. Patentin arvo on funktio sekä patentin että sen haltijan ominaisuuksista. Tämä johtuu osin siitä, että patentista saatavan hyödyn oppiminen vie aikaa ja rahaa. Lisäksi tulokset viittaavat siihen, että pienten yritysten on rahoitusmarkkinoiden puutteelisuuden vuoksi vaikeampi kuin suurten yritysten käyttää hyväkseen patentista saatavaa mahdollista etua. Tutkimuksesta saatu toinen loppupäätös on siis, että jos patentteja pidetään kannustimena tutkimukselle ja kehitykselle, uuden tuotteen tai prosessin kaupallistamista tulisi tukea julkisin menoin myös patentin myöntämisen jälkeen. Keskeinen tulos on niin ikään se, että nykyinen 20 vuoden patenttisuoja on liian pitkä. Optimaalisen patentittijärjestelmän kannalta patentin lakisääteisen pituuden ei tulisi olla yli 17 vuotta.

Asiasanat: patentti, patentin arvo, patentin uusiminen, vuosimaksut, Suomi
JEL-luokittelu: O34, C01

Acknowledgements

I am priviliged to have had the opportunity to carry out my doctoral studies surrounded by so many supportive people. I want to thank some of you here.

First and foremost I would like to thank my supervisior, Director Otto Toivanen, who has helped, encouraged and guided me throughout the project. I cannot imagine having had a better mentor. Also my other supervisor, professor Rune Stenbacka, has been invaluable for completing this project. Thank you not only for insightful comments on the research but also for giving me the encouragement I needed to finish. Besides Otto and Rune, my thanks go to professor Tom Berglund, who was my supervisor during the first years of my graduate studies.

My warmest gratitute also goes to my financiers. Needless to say, without financing there is no project. A large part of this thesis was written while I was at the department of Economics at Hanken. I have also received financial support from the Foundation of the Swedish School of Economics, the Academy of Finland via the Economics of Intellectual Property Rights -project lead by professor Klaus Kultti, FDPE, the Yrjö Jahnsson foundation, Svenska Litteratur sällskapet, and Svenska kulturfonden.

This final manuscript has benefited enormously from comments of my pre-examiners professor Dietmar Harhoff and professor Ari Hyytinen. Their effort in critically evaluating the text are warmly appreciated, and their suggestions helped me take the thesis to another level. I also want to thank Ari Hyytinen for commenting on my presentations in many seminars over the years.

There are many others who have commented on my works in those various seminars. I especially want to thank Tuomas Takalo for being genuinly interested in my research and always discussing it without even being asked.

In addition to the Hecer seminars, another forum that has been invaluable for my development is the Industrial Organization group and its regular meetings. I feel immensely lucky to have had the opportunity to work with this group. Thank you Janne, Lotta, Mari, Tanja, Torsten, and Valtteri. Your ambitions and enthusiasm inspired me to achieve more.

Another group of people I want to thank are my friends and colleagues: Heidi, Joacim, Laura, Ondrej, Michal, Mikael, Staffan and Xavier. Not discussing my so-called research over lunch has been very important for me. Staffan Ringbom deserves a special thanks at this stage, not only for being like a supervisor, but also for commenting on my work and life in general at many seminars, discussion groups, and lunch and coffee breaks. You were also the one who encouraged me to start on my PhD studies. I have not always been thankful for that − but I certainly am now.

A third group of people who deserve my gratitude are my friends and family. It has been good to know that even though you are not up to date on what I do, you always support me.

Last I want to thank Henrik. Your support and patience throughout the project has been invaluable. When I was in doubt you encouraged me, and when I lost focus you reminded me of what is important. Thank you.

Helsinki, March 2009
Charlotta Grönqvist

Contents

*With kind permission from Springer Science and Business Media: The Journal of Technology Transfer, The private value of patents by patent characteristics: evidence from Finland, vol 34, 2009, page 159, Grönqvist Charlotta.

Introduction

Contents

1 Background

Innovation is important for economic growth. Already Schumpeter (1911) argued that innovation, and especially technical innovation, is one of the driving forces behind economic growth. Growth accountants during the 1950s and 1960s showed empirically that a large part of the increase in economic growth cannot be accounted for by an increase in capital or labor and must be a result of increased productivity (Abramovitz 1956, Kendrick 1956, Solow 1957).[1] Today the importance of innovation is well understood by governments. Investment in research and development (R&D) is an important part of national policies in the global economy. The objective of the European Union is to invest 3 % of GDP in research by 2010 (European Council 2002). In Finland R&D amounted to 6.2 billion euros in 2007. This was almost 3.5% of GDP.[2]

But, producing innovations is not the same as manufacturing normal products. Arrow (1962) argues that there are three factors that hinder perfectly competitive markets from producing the optimal level of innovations. First, innovation is information, which is a public good[3], and therefore innovation lacks natural proprietary rights. When natural proprietary rights are missing, it may be difficult to internalize returns from innovation. As firms invest only if returns are higher than the costs, investments in innovations will not be undertaken if revenues are hard to internalize. Second, investments in innovations are risky. Innovators cannot in a fully competitive market, capture returns from innovation that would justify the risk taken. Third, investments in innovations are benign to increasing returns. Investments in innovation usually demand a high initial cost, but once the innovation occurs, the marginal costs is typically low. In a perfectly competitive market with no barriers to entry, goods are priced at marginal costs, and this price is not high enough to cover the initial investment.

Hence, innovators will not have the incentive to invest in innovation even though innovation is subsidized. According to Arrow (1962), intellectual property rights can to some extent ameliorate the problem of inappropriability. The importance of intellectual property rights

[1]In United States output per hour worked in 1970 was more than 10 times as high as in 1870, and in Finland work was 14 times more effective in 1970 than a century earlier (Maddison 1982, Vartia and Ylä-Anttila 2003).

[2]Statistics Finland. http://www.stat.fi/tkl/tkke_2007_2008-10-23_tie_001.html accessed on 15 Nov 2008.

[3]A public good is a good that is non-rival and non-excludable (Cornes and Sandler 1986).

(IPR) to ensure economic growth is theoretically shown by endogenous growth models (Romer 1990, Aghion and Howitt 1992, Barro and Sala-i-Martin 1995). In endogenous growth models, competition between profit maximizing innovative firms generates technological progress, and the incentives to innovate come from the intellectual property rights. O'Donoghue and Zweimüller (2004) formalize how specifically patent policy will affect growth in a general equilibrium framework.

Unfortunately intellectual property rights, and especially patents are a second best solution. While a patent gives the innovator a monopoly for a certain time and therefore helps the innovator internalize research and development investment, patents also lead to a welfare loss.[4] Thus, the benefits of the patent system to the society are increased incentives to innovate (via easier internalization of investments in research and development), increased diffusion of new knowledge, and easier commercialization of patented innovations (Machlup 1958). The drawbacks of the patent system are the monopoly that it creates for a certain time period[5] and there are costs in maintaining a large administrative force.

From a welfare point of view, a patent system should exist if the benefits from patents are larger than the costs. Therefore, the fundamental question that has interested researchers is: does the patent system increase welfare?[6]

In the following section I briefly summarize results from research that tries to shed light on this complex question. I focus on the literature on patents as incentives and touch in the end briefly on the literature on how patents diffuse information and ease commercialization. In section three I outline my contribution to this discussion.

[4] Given the assumption that it does not matter whether the surplus accrues to consumer or producer, there would be no welfare loss if the patent owner was allowed to price discriminate (Nordhaus 1967).

[5] 20 years in Finland.

[6] Patents are not the only way of encouraging firms to innovate. As noted above, countries invest a large share of their GDP in research and development. Patents are an ex-post renumeration whereas a R&D subsidy policy or a fiscal policy encouraging innovation in investment are ex-ante rewards. Here I will not focus on the differences between ex-ante and ex-post compensation. For a thorough analysis of the effects of R&D and tax-based subsidies see Tanayama (2007) and Hall and Reenen (2000).

However, patents are, in contrast to eg trademarks or registered designs, by definition linked to technical development. A patent is granted for an industrially applicable invention and this invention has to be novel and differ from previous innovations. Moreover, patents are not only in theory linked to technical development; Pakes and Griliches (1980, 1984) find that there is a relationship between R&D and the number of patents.

2 The Economics of Patents

The debate on the welfare effects of the patent system is not new (see Machlup and Penrose (1950) for a review of the debate of the nineteenth century). The question that researchers are interested in is whether the benefits of the patent system (incentives to innovate, diffusion, commercialization) outweigh the costs of the patent system. To answer this question, most researchers have focused on each of the benefits separately, ie incentives to innovate, increased diffusion, and easier commercialization. In this section I review each of these three research directions starting with the line of research that has attained most attention.

2.1 Patents as incentives

This subsection summarizes research on patents as incentives to innovate. This question has been approached from different angles. First, there is general research on whether patents create incentives to innovate. Second, researchers have taken a normative approach and modeled the optimal patent system. A third way, ie a positive approach, is to quantify the amount of money that can be internalized through patents. This is done by estimating the private value of patents. The private value of patents is an estimate of how much more profit the innovator earns if he renews the patent compared to the situation where the patent is not renewed.

2.1.1 Do patents create incentives to innovate?

The traditional argument among economists is that due to problems in internalizing investments, firms will under-invest in R&D, so that it is socially beneficial to increase their incentives to innovate. There is also empirical evidence that supports this view; social rates of return to R&D are higher than private rates of returns (Griliches 1992, Jones and Williams 1998). Arrow (1962) argues that when there are asymmetries in information between innovator and government, patents are one way of addressing this problem of under-investment in R&D.

Nelson and Winter (1982) challenge the view that patents are needed to encourage firms to innovate. They are supported by empirical research. Numerous researchers have established that patents are seldom the best way of appropriating investments in

R&D projects and that patents effectively protect only chemical and pharmaceutical innovations (Scherer 1983, Levin et al. 1987, McLennan 1994, Harabi 1995, Rausch 1995, Arundel and Kabla 1998, Cohen et al. 2000, Arora et al. 2008, Moser 2005).

Models taking into account the cost of imitation also raise doubts about the need for patents as a means to increase innovation. Hellwig and Irmen (2001) and Boldrin and Levin (2002) show that when imitation is as expensive as R&D, patents are not needed. Mansfield et al. (1981) estimate that imitation costs amount on average to 65% of innovation costs and that the imitation time is also substantial. This would indicate that patents are needed at least to some extent. Bessen and Maskin (2006) however argue that patents are not needed at all. They show that even if imitation is free, patents are welfare reducing when innovation is sequential and complementary.

More sophisticated models that take into account simultaneous innovations and collusion find that patenting dominates secrecy and that patents can hinder collusion (Kultti et al. 2007a, Kultti et al. 2007b). Also, Carpentier and Kultti (2006) show that when innovation is cumulative and R&D investments are endogenous there is more innovation with a patent system than without.

On the other hand, instead of merely challenging the view that patents increase innovation, many authors claim that patents actually hinder innovation (Jaffe and Lerner 2004). The intuition is that firms patent for many reasons other than to protect their innovation; patents are assets in collaborations, patents grant access to capital markets, patents are used as performance indicators, and often researchers' renumeration is tied to the number of patent applications (Blind et al. 2007). Ultimately, the reason for researchers arguing that the patent system decreases incentives to innovate is that that patents are used as strategic weapons and are themselves the goal, not the underlying innovation (Macdonald 2003). However, while there is evidence that patents are important strategic devices (Cohen et al. 2002, A. Arundel and Soete 1995, Blind et al. 2006, Schankerman and Noel 2006), there is not much empirical data suggesting that patents reduce innovation because they are used for strategic purposes.

Empirical evidence on whether patents increase innovation is like the theoretical contributions, contradictory. Taylor and Silberston (1973), based on evidence from 27 UK firms, and Mansfield (1986), based on US evidence, find that R&D spending would be only marginally lower in most industries if the patent system were abolished. On the other hand, Granstrand (1999) finds that R&D budgets in Japan would decrease by almost 40% in the absence of patent protection. Also Kanwar and Evenson (2003) find that patents have a positive influence on R&D investment.

Empirical evidence on whether stronger patent laws increase incentives is also inconclusive. Sakakibara and Branstetter (2001) find that strengthened patent laws in Japan increased neither innovation nor output, but Hall and Ziedonis (2001) and Bessen and Hunt (2007) found that strengthened patent laws in the US increased patenting among entrants in the semiconductor industry and software firms respectively. The latter result may, however, stem from the fact that patent laws do not so much increase the rate of innovation as the direction of innovation (Moser 2005). The Bayh-Dole act of 1980, which encourages universities to patent and license, has also been used as a natural experiment to explore how universities react to stronger patent protection. Results show that the university patenting increased after the Act, but the results are inconclusive as to whether the quality of patents also changed (Sampat et al. 2003, Hendersson et al. 1998). In addition to the above studies on one country, there are also cross country studies. Kanwar and Evenson (2003) test whether stronger IPRs increase technological change and find that countries with stronger patent protection invest a larger share of GNP in research and development. Ginarte and Park (1997) analyses the effect of IPRs on growth and find that IPR stimulates innovation (R&D spending). But, the newest study using cross country data and the most advanced empirical methods, ie the study by Qian (2007), does not find that innovation activities in the pharmaceutical industry would be encouraged by national patent protection.

2.1.2 The optimal patent system

There is no consensus on the effects of patents on innovation, and perhaps for this reason researchers have striven to design a patent system that minimizes the loss in social welfare and also creates incentives to innovate. Nordhaus (1969, 1972, 1967) is the first to address the question of an optimal patent system based on optimal patent length. He thinks of patents as a policy instrument for increasing economic growth.

The optimal patent system has later been modeled based on optimal patent breadth or on the tradeoff between breadth and length. Various assumptions regarding competition, imitation, endogenous entry, and patent races have been considered (Klemperer 1990, Gilbert and Shapiro 1990, Gallini 1992, Dijk 1996, Wright 1999, Denicolò 1996, Kanniainen and Stenbacka 2000). The results from these models are somewhat contradictory, but Takalo (2001) shows that optimal patent policy is determined by the effect that the marginal rate of substitution of patent length for perfect patent protection has on incentives to innovate and on social welfare. The models on one innovation have been followed by a myriad of models on the optimal patent systems when innovation is multistaged or when innovation is cumulative or sequential (Scotchmer and Green 1990, Scotchmer 1991, Green and Scotchmer 1995, Chang 1995, Scotchmer 1996, Matutes et al. 1996, VanDijk 1996 O'Donoghue et al. 1998, O'Donoghue 1998).

Instead of designing the optimal patent system as a function of patent length or breadth, Wright (1983) expresses the optimal invention incentive as a function of the probability of success and the elasticity of the supply of research. He argues that patents may not always be the optimal incentive mechanism. Scotchmer (1999) designs the optimal incentive scheme and shows that when information is asymmetric, a renewal mechanism, together with a subsidy, may be optimal. Cornelli and Schankerman (1999) also argue that patent fees can be used as an incentive device and conclude that patent lives should optimally be differentiated, whereas Llobet et al. (2000) claim that when innovation is cumulative, the optimal incentives are provided by compulsory licensing.

To sum up: there has been much research on the optimal patent policy, but most models fail at including the indirect effects that patents have, eg via strategic patenting and on incentives to innovate. Thus, there is not yet a well-developed welfare analysis of the patent system.

There is also not much empirical research on the optimal patent policy. There are two empirical papers that touch on the optimal patent policy. Both these papers use historical data. Lerner (2002) investigates whether the differences in the strength of patent laws across countries correspond to the theory of Nordhaus (1969). According to Nordhaus (1969), a country that is a technological leader (ie has relative economic strength) should have stronger patent protection than a follower. Lerner (2002) uses historical patent data from sixty countries to determine whether this is true. Moser (2005), on the other hand, empirically investigates how different patent laws influence innovation using data from 19th century world fairs. She finds that patent laws do not so much affect the amount of innovation as the areas in which innovations occur.

In addition to the above empirical approaches, we have some information about optimal patent length based on theoretical models on the optimal patent policy. Nordhaus (1967) calculates the optimal life of patents by assigning reasonable values to the parameters in his theoretical model. He finds that the optimal patent life for an average, non-drastic innovation is 9 years. Denicolò (2007) proceeds in a similar way. He calculates whether innovators obtain excessive returns from patents by, based on previous empirical estimates, assigning reasonable values to parameters in his model. His conclusion is that patents do not generate excessive rewards to assignees.

Finally, Deng (2007a) finds that both changes in statutory limit and renewal fee schedule had only a modest impacts on the mean private value of patents, and Deardorff (1992) finds that extending the patent from one country to a large share of the world reduces world welfare.

2.1.3 Empirical evidence of the private value of patents

Instead of focusing on a hypothetical optimal patent system researchers have focused on the patent system in force. Hence, a large part of the empirical work on patents as incentives has focused on estimating the private value of patents. The private value of the patent is the amount of additional profit the assignee obtains if he renews his patents compared to letting the patent lapse.[7] The private value distribution of patents are calculated using patent renewal rates and fees.[8]

Pakes and Schankerman (1979) initiated the research in which renewal fees and rates are used to calculate the private value of patents. The intuition behind this approach is that the patent owner

[7]The private value of patents is interesting not only to the academic researchers, but also to company owners, investors and banks. Shapiro and Hassett (2005) estimate that 70 percent of the current value of equities in the United States comes from intangible assets, eg patents. Moreover, the increased use of patents as collateral for securitization and lending raises the importance of valuing patents properly (Hillery 2004). Estimates of the private value of patents is also of interest to competition authorities that need to assess eg the effect of firms’ patents on market power.

[8]Instead of estimating the distribution of the private value of patents, researchers have also tried to evaluate which factors determine the private value of patents. This has been done in two ways. One way is to assess the value by direct surveys and learn how different factors affect this reported value (eg Harhoff et al. 1999, Harhoff et al. 2003a, Scherer and Harhoff 2000, Harhoff et al. 2003b, Gambardella et al. 2008 and Kaiser 2006). Another way is to regress on proxies for patent value, eg citation-weighted patent counts (Duguet and Iung 1997, Svensson 2006, Maurseth (2005), Sapsalis et al. 2006, Reitzig 2003 and Lanjouw and Schankerman 2004).

renews the patent as long as the revenues from the patent exceded the costs of keeping the patent in force (renewal fees).[9]

The earliest studies in this line of research used aggregate data, ie information about the proportion of patents renewed yearly, to infer the value of patents. Schankerman and Pakes (1985, 1986) use a model of perfect foresight and conclude that the distribution of the value of patents is highly skewed. The private value of patents has later been shown to differ by technology, by the nationality of the inventor, by the designated country of patent protection, and by the type of patent (Schankerman 1998, Deng 2007b, Koléda 2005, Fikkert and Luthria 2000). Putnam (1996) includes the cost of application and Lanjouw et al. (1996) illustrate how estimates of the value of patent protection vary under alternative legal rules and renewal fees.

Schankerman and Pakes' (1985, 1986) patent renewal model is restrictive because it assumes that revenues are deterministic, ie that the patent owner knows at the time of application for how long he will keep the patent. Pakes (1986) therefore uses a stochastic model of patent renewals to estimate the value of patents. This model, in contrast to the model of perfect foresight, allows the patent owner to learn how to use the patent more effectively. Lanjouw (1998) and Deng (2005a) have developed the dynamic model further to include the cost of infringement and the decision to apply for a patent. Baudry and Dumont (2006) extend Pakes' model to allow for a wide range of stochastic processes and estimate this stochastic model using French patent data.

Another restrictive assumption of the Schankerman and Pakes (1986) model is that all patents are drawn from the same distribution. Bessen (2008) and Deng (2007b) relax this assumption when they estimate the model of Schankerman and Pakes (1986) with patent level data. Bessen (2008) uses cross sectional US patent data and finds that highly cited patents and litigated patents are more valuable. He also finds that small firms have patents of lower value than large firms. Deng (2007b) concludes that patent value increases with the economic size of the country.

One drawback of parametric modeling is that the results may

[9]As an alternative to this structural approach, researchers have also estimated the relationship between patents and market value of the firm. There is a vast empirical literature that examines how the market values patents(Griliches 1981, Pakes 1985, Cockburn and Griliches 1988, Megna and Klock 1993). Results suggest that patents are valued positively by the market, but there are differences between industries. Hall and MacGarvie (2006) finds that US software patents are more valuable than other patents. Also patents owned by firms with large market shares are valued more than others (Blundell et al. 1999).

depend heavily on the assumed functional form. Pakes and Simpson (1989) therefore suggest that the private value of patents can be tested non-parametrically. They find that the nationality of the patentee, the industry, and the cohort affect all the renewal rates of patents.

2.2 Do patents increase diffusion?

In many countries patents are disclosed 18 months after filing for the patent. Therefore the second claimed benefit of patents is that they increase the diffusion of knowledge. To contribute to the debate on whether patents benefit society, researchers have tried to find whether this claim is true and they have tried to quantify knowledge spillovers from patenting.

The results from theoretical contributions are mixed. The difference in theoretical results is largely dependent on how diffusion is treated. For example, in Denicolò and Fanzoni (2004) imitation is free and and the knowledge in a patent can with certainty be implemented. However, Penrose (1951) argues that the obligation to disclosure information also discourages innovators from patenting. Ultimately, innovations are patented only if diffusion of the new knowledge is delayed. That this also is the case, is demonstrated by Takalo (1998). Takalo (1998) and also Kanniainen and Stenbacka (2000), see diffusion as an endogenized process that comes from costly imitation, and Kanniainen and Stenbacka (2000) show that there is underinvestment in imitation of patented innovations when imitation is a costly and endogenous process. Also Bessen (2005) shows that the patent system does not increase diffusion. Ordover (1991) takes a middle way and argues that well structured patent law and antitrust rules can, at the same time, provide incentives to innovate and diffuse new knowledge.

There is much empirical evidence that knowledge spillovers exist (Jaffe 1986, Trajtenberg 1990, Jaffe et al. 1993), but whether spillovers result from patents has not been studied extensively. The results so far suggest that the diffusion from patents is substantial. Moser (2008) shows that innovation is geographically more diverged in industries with high propensity to patent. This finding suggests that patents increase diffusion. Also Cohen et al. (2002) find that exchange of information is more extensive in Japan than in the US because the patent system in Japan encourages more cross-licensing and aggressive patenting. Deng (2006) finds that the economic value of spillovers is high also in the US semiconductor industry:

she estimates, using patent citations, that an average firm obtains knowledge spillovers that amount to half of its own R&D budget.

2.3 Do patents increase commercialization?

Already Arrow (1962) stressed that patents reduce the transaction costs of innovation and therefore increase commercialization. Comanor and Scherer (1969) also noted that patent statistics can be seen as a measure of input to technology creation rather than innovation output, and Hall (2005) suggests that US patents are a good signal to firms that seek venture capital funding.

Scarce empirical evidence suggests that the patent system indeed enables commercialization, at least in some technologies. Mansfield (1986) finds that two-thirds of pharmaceutical innovations would not be commercially introduced in the absence of patent protection. However, this number is substantially smaller for other technologies. For example, Mansfield (1986) finds that the patent system does not have any impact on the commercialization of textiles innovations. Schmith (1999) and Maskus and Penubarti (1995) find that US firms rather export to countries with stronger patent protection. More specifically, strong patent protection increases exports to countries where imitation is widespread but decreases it to countries where the propensity to imitate is low (Schmith 2001). Finally, Svensson (2007) finds that small and medium sized firms commercialize their patents more often than large companies in Sweden.

3 Contribution, structure and results

This thesis contributes to the literature that quantifies the internalization of patent protection, ie I estimate the private value of Finnish patents. The thesis consists of four independent essays that are closely linked to each other.

Even though the private value of patents is the thread running through all the essays, each essay asks different questions and uses different methods to answer the specific questions. The advantage of estimating the private value of patents in three of the four essays, while changing the method or data, allows me, in accordance with current research in industrial organization, to investigate in detail how the assumptions of the model change the results.

The data consist of Finnish patents, ie instanses in which a Finnish assignee was granted a patent in Finland. The patent data are from the National Board of Patents and Registration of Finland and include all Finnish patents granted between January 1971 and June 2003. Data on annual renewal costs are from reports of the Ministry of Trade and Industry. The basic data are the same for every essay, even though different time periods are used.

There is to my knowledge, with the exception of Pakes and Simpson (1989), no previous research on the private value of Finnish patents. It is particularly interesting to analyze patents in Finland, because as eg Trajtenberg (2001) notes, Finland has rapidly transformed from an agricultural economy to a technology-intensive economy.

The table below concisely summarizes the contribution, main finding, data, and method of each essay, and sub-sections 3.1−3.4 summarize the essays and provide comparisons between them. Subsection 3.5 summarizes the overall conclusion. In the Appendix the institutional details of the Finnish patent system are laid out.

Table 1: Summary of essays

	Essay 1	**Essay 2**
Contribution	Estimates the private value of Finnish patents by applicant, technology, and breadth	Investigates why firm patents are more valuable than patents owned by individuals
Finding	Valuable patents: firm patents, electrical engineering and chemical & pharmaceutical patents	Firms assignees learn how to use the patent faster and better
Data	Granted after 1971 & application before 1990	Granted after 1971 & application before 1984
Method	Non-linear least squares	Simulated method of moments
	Essay 3	**Essay 4**
Contribution	Investigates how financial characteristics of the assignee affect the private value of patents	Estimates empirically the optimal patent length using a patent law change as a natural experiment
Finding	Profitability and worker productivity increase, and size decreases, value The effects of leverage costs on value depend on firm size	Optimal patent length is less than 18 years in Finland
Data	Granted patents applied for in 1988 or 1989	Granted after 1971 & applied before 1982
Method	Random effects probit	Different non-parametric tests

3.1 Essay 1 − The private value of patents by patent characteristics: evidence from Finland

In essay 1 I estimate the private value of patents using the model of Schankerman and Pakes (1986). A large part of the previous research on private value of patents has employed this model to estimate the value distribution of patents from different countries. The paper of Schankerman and Pakes (1986) is a seminal paper in this field, and if one is to study the private value of patents in Finland, the first step is to use this model.

I replicate previous studies and estimate the private value of patents for all patents and disaggregated by technology and by patent assignee. In addition to this I investigate how the private value of patents differs across patent breadth. We have very little empirical evidence on how breadth affects the private value of patents, even though it is widely used in the theoretical literature on the optimal patent system. Also, it is important to know if the patent system provides different incentives to different applicants.

The average private value of patents is 7 551 euros (year 2000 euros). In line with previous research, I find that the distribution of private value of patents is skewed. The number of patents should therefore not be used as a proxy for innovation output. The age of a patent is a better indicator of the value of a patent. Renewing a patent for one more year indicates, on average, a 1.5 times more valuable patent than if it had not been renewed. I also find that there are large differences in private value as between different technologies in Finland. Specifically, chemical and pharmaceutical and electronics have on average ten times more valuable patents than patents from other technologies. I also find that it is not straightforward to assume that broader patents are more valuable than narrower ones. Finally, firm patents are 50% more valuable than individual assignee's patents.

3.2 Essay 2 − Why does private patent value differ by assignee?

In essay 2, I investigate if and why the private value of patents applied for by firms and by individual assignees differ. The motivation is that there is contradictory evidence on how the private value of patents differs by the type of applicant. Also, the differences in the private patent value of different owners has not been examined thoroughly even though it is important to know in order to understand the incentives to innovate arising from patents.

I use the stochastic dynamic model of Pakes (1986) because it allows me to investigate how the revenues from patent protection evolve for different types of assignees. I find that firm patents are 60% more valuable than patents owned by individual persons.

The discrepancy in private values of patents of firms and individual assignees comes from firms being better at learning. Specifically, individual patent owners must accumulate knowledge for a longer period of time and therefore firms can begin to internalize patent revenues sooner. Also, a larger share of firms than individual assignees learn new ways of using patents and the increase in revenues due to learning is also higher for firms.

The estimated private value is lower in essay 2 than in essay 1. Specifically, estimates from the stochastic model used in essay 2 are only about 36% of the estimates from the deterministic model. The main reasons for the differences between the deterministic and stochastic models lie in the assumptions about how revenues evolve.

3.3 Essay 3 − Do the assignee's characteristics affect the private value of patents?

In essay 3, I estimate how the private value of patents depends on characteristics of the patent owner. I examine the relationship between the private value of patents and size, wage costs, profitability and leverage costs. To do this, I extend the model of Schankerman and Pakes (1986) to include yearly shocks. The data set I use is unique, as it combines data on patent renewals with financial characteristics of the patent owning firms.

I find that the private value of the patent is affected not only by the characteristics of the patent, but also by the financial characteristics of the patent owner. I find that smaller firms with high leverage costs have patents of lower value. Together with the finding that more profitable firms have more valuable patents, this finding suggests that firms have to use internal means in appropriating revenues from patents. This indicates that there are financial imperfections and that not only innovation but also commercialization of innovations should be subsidized.

The mean value of patents found in essay 3 is 30 000 euros. The differences between this estimate and the results from essay 1 are mostly due to data differences. But a small part of the difference is a result of the different assumptions regarding the way patent revenues evolve.

3.4 Essay 4 − The optimal patent length is less than 18 years

The question whether we should have a patent system and how it should be designed is not new even though it still is very relevant. However, previous empirical evidence on optimal patent life is almost non-existent. I contribute to the discussion on optimal patent length by using non-parametric techniques. I test how a legal change in the statutory length of patents changed the renewal behaviour of patents in Finland.

I test non-parametrically whether the law reform that extended the statutory life of patents from 17 to 20 years in 1980 changed the renewal rates of patents. The aim with changing patent laws is naturally not to change the renewal behavior, but to design an optimal patent policy that balances the trade-off between incentives to the innovator and the welfare loss from patents. Renewal rates, together with non-parametric tests, can be used to draw conclusions about the optimal patent length.

I find that the change in the patent law did not change the renewal behavior. I also find that the private value of patents did not increase after the statutory length was prolonged. These results suggest that the optimal patent length is less than 18 years in Finland and consequently that the change in the patent law was not optimal.

3.5 Conclusions

This thesis investigates the private value distribution of Finnish patents. I present two overall policy recommendations based on the findings.

First, I find that the distribution of the private value of patents depends on patent characteristics as well as owner characteristics. This derives from the fact that it takes time and money to learn the private value of a patent. Also, there seem to be financial imperfections that restrict the internalization of patent revenues for smaller firms. If patents are seen as a good incentive mechanism for innovation, the policy implication is that commercialization of patented innovations should be supported.

Second, I find, using a a patent law change as a natural experiment, that the statutory patent length of 20 years is too long. The optimal patent length is shorter than 18 years in Finland.

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A The patenting process in Finland

This appendix summarizes the institutional factors of the Finnish patent system. First I describe the application and grant process. Second I discuss briefly the renewal of patents and, finally I touch on the Finnish patent system in an international context.

A.1 Application and grant process

The application procedure of a national patent at the Finnish Patent and Registration office consists of four stages. These stages are illustrated in Figure A1. The patent office's actions are depicted in the middle. To the left, is a description of the actions of the assignee when the patent is granted. The assignee's actions in case of rejection are outlined to the right.

The first stage is application. The patent applicant pays the application fee and provides the examiner with all necessary documents. The necessary documents for an application are the application form, a description of the innovation, the claims, and a summary. The description of the innovation is important because it contains all necessary technical details of the innovation. The description should also include the technical level of the innovation, ie the closest substitutes should be named. The claims are important because they define the patent. Given that the formalities are met, the patent application can continue to the second step.

The second stage in the application process is the examination stage. The examination process usually takes between 6 and 9 months after the application date. During this stage, the patent examiner finds out whether the innovation meets the requirements of a patent. To determine whether the innovation is novel, the researcher must relate the innovation to previous patents. The starting point for the research is the information on the technical level in the description, but the research is not limited to this. The examiner can also refer to already existing patents, academic journals and other literature in the examination process. During the second stage the innovation is also given the IPC classification. Sometimes the patent is given several IPC classifications, but such that the first is the one that best describes the innovation (Patenttikirja 2008).

Once the pre-examination process is completed, the patent owner is informed and the applicant can respond to the result of the pre-examination, usually within 6 months. If the examiner concludes that the patent can be granted, the applicant must pay the printing fee. The patent is granted when it has been printed in the Patent Gazette. This is the third stage.

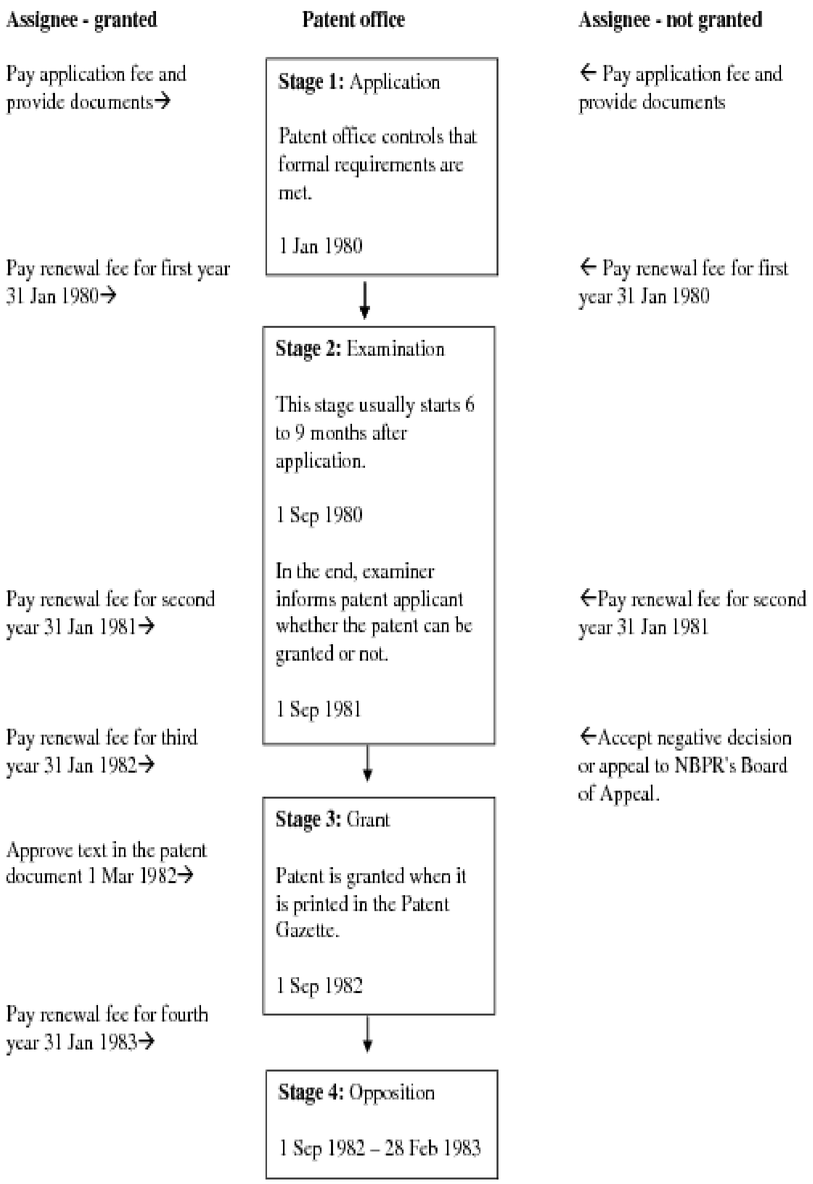
As it is very difficult for the examiner to judge whether the patent has not been used before, there is a fourth phase during which others can lodge oppositions. The opposition phase lasts for 9 months, starting when the patent is published in the Gazette. During this process, eg competitors can provide the examiner with information about the innovation. If an opposition is lodged, a patent examiner re-examines the innovation.

If the patent examiner, in the second stage, finds that the innovation does not meet the standards of a patent or if an opposition is lodged showing that the innovation is not novel, the patent is not granted. However, there are always two examiners deciding on the rejection of an application.

In case of a rejection, the patent applicant can appeal to the National Board of Patents and Registration's (NBPR's) Board of Appeal. In case of a rejection from the Board of the Appeal, the patent applicant can, within 60 days, appeal to the Supreme Administrative Court.

The average delay between application date (stage one) and grant date (stage three) is, according to the National Board of Patents and Registration 2–2.5 years in Finland. My data set consisting of all granted Finnish patents after 1 Jan 1971 shows that the lag between application and grant is almost three years for granted patents. The granting process was longer during the 1970s than in the 1980s and 1990s. In the 1970s the lag was 3.4 years and in the 1980s and 1990s it was 2.8 and 2.9 respectively. The spread of the examination of the patents that eventually were granted was greater in the 1970s than in the 1980s and 1990s. 95% of the patents in the 1980s and 1990s and 90% of patents in the 1970s had lags shorter than 7 years.

Figure A1: Patenting process



A.2 Renewal of patents

The statutory length for patents in Finland is 20 years, since it was changed in June 1980 from 17 years to 20 years. The reason behind the change was to harmonize the Finnish system with the majority of West European countries. This was also a step toward joining PCT and EPC.

However, a patent is not automatically in force for 20 years. To keep the patent, the assignee must pay a yearly renewal fee. This fee has to be paid even though the patent is not yet granted. For example, for a patent that was applied for in January 1980 and granted in December 1981, renewal fees were paid for the years 1980 and 1981 at the end of January 1980 and 1981, even though the patent was not yet granted.

The fee structure changed in 1990. Today the fees for the first two years are paid together with the fee for the third year. Thus, for patents applied for in January 1990 and granted in December 1991, renewal fees were paid for the years 1990 and 1991, but they were charged together with the third renewal fee at the end of January 1992.

A.3 Finnish patent system in the international context

Since March 1996 Finland has belonged to the European patent convention. Under the European patent convention, one can obtain a patent for 30 European countries by filing a single application. European patents are however not a supranational patent but a group of national patents. Therefore, a European patent that has been granted must be validated in each country. In practice the validation in Finland is done by providing a translation of the documents within three months from grant of the patent. The European patents are, as national patents, kept valid by paying the renewal fees.

In this thesis I use only Finnish patents applied for by Finnish firms or individuals before 1990 via the national route. Therefore the issue of national versus international patent protection is not discussed in the essays (EPC, PCT). Please consult Yi Deng's dissertation on the private value of European patents and the papers based on this dissertation (Deng 2005a,b, 2007b,a, 2003) for discussions of both the nature of European patents and the differences in the value distribution between national and European patents.

Essay 1: The private value of patents by patent characteristics: evidence from Finland*

Contents

*With kind permission from Springer Science and Business Media: The Journal of Technology Transfer, The private value of patents by patent characteristics: evidence from Finland, vol 34, 2009, page 159, Grönqvist Charlotta.

Abstract

I use renewal rates and fees to estimate the private value of Finnish patents by patent characteristic. I disaggregate the value estimations by applicant, patent breadth, and technology. Firm patents are 1.5 times more valuable than patents owned by individuals. This holds also when controlling for technology and breadth. There are large differences in values between technologies but in contrast to the usual assumption made in the theoretical literature, broader patents are not necessarily more valuable than narrower ones. Patent value is skewed and therefore the number of patents should be weighted by an index when measuring technological change. I construct this index for Finnish patents and find that renewing a patent one more year signals a 1.5 times more valuable patent.

1 Introduction

The patent system serves three purposes; it increases incentives to innovate, it increases diffusion of knowledge and it enables commercialisation (Machlup 1958). Whether these benefits outweigh the costs of patents, ie the welfare loss and the administrative costs, has been the motivating question for much of research in economics of patents. The question of whether the patent system supports innovation and economic growth is complex to test empirically and therefore researchers have quantified incentives, diffusion, and the effect on commercialisation separately.

The purpose of this paper is to estimate the private value of Finnish patents, ie to quantify the incentives provided by the patent system. The private value of patents is the utility that the patent owner gets from a patent. It consists of the exclusive right that the patented invention is granted. I estimate the value of patents using renewal rates and fees.

I disaggregate the value estimations by new dimensions, applicant type and patent breadth. Patent breadth has received attention in the theoretical literature on optimal patent design, where it is assumed that broader patents are good for the innovator but harm the society (eg Klemperer 1990, Gilbert and Shapiro 1990). Lerner (1994) finds that broad patents affect positively the valuation of firm. However, whether broader patents leads directly to higher patent value has not been tested before.

By controlling for the type of applicant we gain insight into whether firms' patents are more or less valuable than those of private persons. If there are differences between firm and private patent values after having controlled for technologies, the value of patents does not only depend on the underlying technology but also on the characteristics of the innovator.

I also examine how the private value of patents differs between technologies. Previous researchers have shown that the private value of patents differs by technology (Schankerman 1998, Deng 2007). I examine what technologies are the most important for Finland. This is interesting because, as Trajtenberg (2001) notes, Finland has rapidly transformed from an agricultural economy to a technology intensive economy.

Researchers estimate the private value of patents in three ways. One is to assess the value directly from surveys (Scherer and Harhoff 2000, Harhoff et al. 2003), another is to estimate firms' market value or profit as a function of its patents (Hall et al. 2005, Hall and MacGarvie 2006) and a third is to use patent renewal fees and rates (Schankerman and Pakes 1986, Pakes 1986). Pakes and Schankerman (1979) initiated the research in which renewal fees and rates are used to calculate the private value of patents. The intuition is that the patent owner keeps the patent if the revenues from the patent are larger than the cost of renewing the patent, ie the yearly renewal costs. Schankerman and Pakes (1986, 1985) use a model of perfect foresight and conclude that the distribution of the value of patents is highly skewed. The private value of patents has later been shown to differ by industries, by the nationality of the inventor, by the designated country of patent protection, and by the type of the patent (process or product) (Schankerman 1998, Deng 2007, Fikkert and Luthria 2000). As an alternative to estimating patent value parametrically Pakes and Simpson (1989) use renewal fees and renewal rates to non-parametrically estimate the private value of patents. They find that patent renewal curves differ by industry, by cohort, and by the nationality of the inventor.

I find that the mean value of Finnish patents is marginally smaller than estimates for larger European countries (Schankerman 1998, Deng 2007, Koléda 2005). However, there are large differences in mean value across technologies. Chemical, pharmaceutical and electrical engineering patents are ten times more valuable than patents from other technologies. Thus, the patent value depends on the characteristics of the innovation. I also find that the value depends on the characteristics of the innovator: firm patents are 1.5 times more valuable than private patents. Furthermore, this relationship holds when controlling for the technology and breadth. Thus, the incentives provided by the patent system depend on the innovation and innovator characteristics. However, I do not find that broader patents are more valuable than narrower patents. Thus, the assumption that broader patents give higher incentives than narrower ones, does necessarily not hold. I also find that the distribution of Finnish patent value is skewed and therefore patent counts are not a good measure for innovation output.

I review the model by Schankerman and Pakes (1986) in section 2. Section 3 describes the data. In section 4 I report the results and section 5 concludes.

2 The model

I use the model by Schankerman and Pakes (1986), in which the patentee chooses how many years he wants to keep a patent in order to maximize the private value of the patent. The patent owner maximizes his private value of the patent by maximizing the discounted value, $V(T)$, of net returns $max_{T\in[1,2,....\bar{T}]}V(T)=\sum_{t=1}^{T}(R_{tj}-C_{tj})(1+d)^{-t}$, where C_{tj} denotes renewal fees at time t for a patent from cohort j, R_{tj} is the return from patent protection, d stands for the interest rate and $\bar{T}$ is the maximum life of patents (20 years). T is the optimal patent length.

Renewal fees, C, are non-decreasing in age and revenues, R, are non-increasing in age. The latter assumption means that revenues at time t can be expressed as a function of initial returns: $R_{tj} = R_{0j}\prod_{\tau=1}^{t}(1-\delta_{\tau j})$, where δ is the decay rate and R_{0j} are initial returns for cohort j. Thus, the patentee will renew a patent at age t only if $R_{0j} \geq C_t\prod_{\tau=1}^{t}(1-\delta_{\tau j})^{-1}$.

Let $F(R_{0j};\theta_j)$ denote the cumulative distribution function of initial revenues, with θ_j indicating the vector of parameters. The proportion of patents renewed in age t from cohort j, P_{tj}, is then $P_{tj}=1-F(R_{0j};\theta_j)$. Thus, knowing the proportion of patents renewed every year and the cost of renewal we can estimate the distribution of initial returns and the decay rate and hence the private value of patents.

3 Data

The data are from the National Board of Patents and Registration of Finland. It includes all granted Finnish patents after January 1971. The annual renewal costs are from the reports of the Ministry of Trade and Industry.

In the estimations I only use patents before 1990 because in 1990 the renewal fees were changed so that they are no longer increasing in age. The patent office granted 9 777 patents during 1971−1989 in Finland. But, the number of granted patents per year has increased so that in 1989 the patent office granted three times more patents than in 1971. The increase in granted patents is a result of more firm patenting. One explanation to the increase in firm patenting is that the number of patenting firms has grown over the years: while during the 1970s about 500 different firms patented, during the 1980s the number was the double.

About two thirds of the patents are firm patents. This ratio is however not constant. While 40% of patents were private patents in 1971, the number had declined to 30% in the 1980s. This is similar to the trend that took place in the first part of the 20th century in US. Schmookler (1966) found that the proportion of firm patents increased from 19% in 1901 to 64% 1960 in the US.

The mean patent length in the data set is 9.97 years, but it has also changed over the years. Patents applied for before 1980 have a mean length of 9 years. Patents applied for during 1980s have a mean length of 12 years. Almost 8% of all patents from the 1970s reached the maximum life of 20 years whereas 12% of the patent applied for between 1980 and 1984 were renewed for 20 years.

I use the international patent classification (IPC) system to construct technologies. Technologies are combinations of IPC classes that should protect inventions of the same kind. I construct six technologies, based on Nikulainen et al. (2005). The six technologies are chemicals and pharmaceuticals (che), consumer goods and civil engineering (con), electrical engineering (ele), instruments (ins), mechanical engineering (mec), and process engineering (pro). 31.40% of patents belong to mechanical engineering patents, and the second largest group is process engineering patents (25.70%). However, the distribution between different fields has changed over time. The share of electrical engineering patents has increased, whereas the percentage of consumer goods and civil engineering patents and mechanical patents has decreased.

The breadth of a patent measures the degree of patent protection. Different definitions of breadth are used in the theoretical literature but breadth has not gained much attention in empirical work. One exception is Lerner (1994), who measures breadth as the number of four digit IPC classes assigned to a patent. I also use the IPC to measure breadth, but I make use of the hierarchical structure of the IPC system. There are nine hierarchies in the IPC system that I label from 0 to 8. 0 is the highest hierarchy, ie the most general level of classification. 23% of the patents are very broad ie belong to the highest hierarchy, whereas 41.50% of the patents are assigned to the second broadest group of patents. The measure of breadth used here corresponds fairly well to the definition of Klemperer (1990) and Waterson (1990) where breadth is defined as the space between the patented product and the nearest substitute.

Patent owners must pay a renewal fee to keep a patent. The renewal fee schedule is increasing in age and it is equal for all patents. The Ministry of Trade and Industry adjusted the renewal fees with the price level so that there are no large real changes between years. I converted the annual fees to euros and discounted to the level of year 2000, using an index for business investments (OECD:Economic Outlook, FIN Deflator for Business Investment, FINEOC00).

4 Results

First I estimate the mean, μ, and standard deviation, σ, of the initial distribution and the decay rate, δ, using non-linear least squares (Table I). I then use these parameters to simulate the value (Table II). I present the results for the whole sample and disaggregated by applicant, technology, and breadth, ie every estimation is done separately for each type of applicant, technology and breadth. Last I estimate a value based index for the whole sample (Table III).

4.1 Parameter estimation

Following previous work, eg Schankerman and Pakes (1986), I assume that the initial returns are log normally distributed. The log of initial returns, r_{0j}, is therefore normally distributed, $r_{0j} \sim N(\mu_j,\sigma_j)$ with mean μ_j and standard deviation σ_j. When the decay rate is constant the renewal decision becomes $\frac{r_{0j}-\mu_j}{\sigma_j} \geq \frac{lnC_{tj}-t*ln(1-\delta_j)-\mu_j}{\sigma_j}$. Since r_{0j} is normally distributed, the proportion of patents that drops out is given by $1-P_{tj} = \Phi(z_{tj};\theta_j)$, where Φ is the standardized normal distribution, $z_{tj} = lnC_{tj} - t * ln(1-\delta_j)$.

Schankerman and Pakes (1986) estimated that the decay rates had fallen in Germany and United Kingdom from the 1950s to the 1970s. To take into account a changing decay rate I allow the decay rate to be different over time. The results are robust for different specifications and I here report the results when there are four different decay rates during the period 1971−1989: one decay rate between 1971−1974, and another between 1975−1979, 1980−1984 and 1985−1989 respectively.

The decay rate has on average been 9−10% (Table I). In contrast to Schankerman and Pakes (1986) I cannot conclude that the decay rate has changed much over the time. However, the big differences in decay rates are found when comparing technologies against each other. While electrical engineering and chemical and pharmaceutical patents have a decay rate as high as 24% and 21% respectively, the decay rate for instruments is only 5−8 %. There are also differences in decay rates between patents of different breadths: narrower patents decay faster than broader patents. One possible explanation for this result is that broader patents are more general and therefore also less likely to become obsolete.

The mean initial return of firm patents is more than 10 % higher than the corresponding mean of private patents (table I). Chemical and pharmaceutical patents have the highest mean (8.13) of the different technologies. Narrower patents have higher means than broader patents. For example the mean of patents from breadth 3 is 6.74, whereas the mean of the broadest patents is 6.05. Thus, broad patents have a low initial distribution and decay at a slow pace, whereas narrow patents have a higher initial distribution but become obsolete at a faster pace.

I find that there is a positive correlation between a high decay rate and a high mean (Table I). I also find that the standard deviation is higher for groups with higher means, thus there is a positive correlation between the mean of the initial distribution, the standard deviation, and the decay rate.

Table 1: Estimates for standard deviation and mean of the initial distribution of returns and the decay rate. Standard deviations are in parentheses.

	all	firm	private	che	con	ele	ins
σ	1.49***	1.39***	1.36***	2.26**	1.40***	1.86***	1.14***
	(.054)	(.061)	(.060)	(.118)	(.081)	(.197)	(.084)
μ	6.35***	6.39***	5.99***	8.13***	6.33***	7.48***	5.72***
	(.218)	(.249)	(.237)	(.484)	(.333)	(.440)	(.339)
δ **7174**	.10***	.08***	.08***	.24***	.08***	.16***	.08***
	(.009)	(.009)	(.010)	(.019)	(.013)	(.017)	(.014)
δ **7579**	.09***	.08***	.07***	.24***	.07***	.16***	.06***
	(.009)	(.010)	(.010)	(.019)	(.012)	(.017)	(.014)
δ **8084**	.10***	.09***	.08***	.23***	.07***	.21***	.05***
	(.009)	(.009)	(.010)	(.019)	(.012)	(.017)	(.014)
δ **8589**	.10***	.08***	.10***	.22***	.08***	.18***	.05***
	(.009)	(.009)	(.010)	(.018)	(.012)	(.017)	(.014)
n	379	379	379	253	329	278	288
	mec	**pro**	**b0**	**b1**	**b2**	**b3**	**b4−8**
σ	1.27***	1.46***	1.31***	1.47***	1.35***	1.59***	1.24***
	(.070)	(.091)	(.062)	(.061)	(.066)	(.100)	(.652)
μ	5.96***	6.23***	6.05***	6.32***	6.20***	6.74***	6.01***
	(.282)	(.371)	(.253)	(.248)	(.269)	(.405)	(.026)
δ **7174**	.07***	.09***	.07***	09***	.08***	.15***	.03***
	(.012)	(.015)	(.010)	(.010)	(.011)	(.016)	(.026)
δ **7579**	.06***	.07***	.06***	.09***	.07***	.12***	.06***
	(.012)	(.015)	(.010)	(.010)	(.011)	(.016)	(.025)
δ **8084**	.07***	.08***	.07***	.09***	.08***	.13***	.05***
	(.011)	(.014)	(.010)	(.010)	(.010)	(.016)	(.026)
δ **8589**	.07***	.08***	.06***	.10***	.06***	.14***	.08
	(.011)	(.014)	(.010)	(.010)	(.010)	(.016)	(.215)
n	357	351	379	379	379	370	249

***,**=significant on a 1%, 5% level, σ= std.dv, μ= mean, δ 7174= decay rate for cohorts 71−74, n=number of cohort/age cells, che=chemicals and pharmaceuticals, con= consumer goods and civil engineering patents, ele= electrical engineering patents, ins=instruments, mec=mechanical engineering patents, pro=process engineering patents, b0=broadest patents, b4−8=narrowest patents

4.2 Value of patent rights

To estimate the distribution of private patent value I first draw a sample of 50 000 pseudo random draws using the estimates of the mean and standard deviations from Table I. I then calculate the optimal life, T, of the patent. Finally I calculate the private present value of Finnish patents, $V(T) = \sum_{t=1}^{T}(R_{tj} - C_{tj})(1+d)^{-t}$. Table II depicts the distribution of the private value of patents for the whole sample and disaggregated by type of applicant, technology, and breadth.

For several reasons the estimated value is the lower bound of the private value of a granted patent. First, I only use patents owned by Finnish firms and persons. Pakes and Simpson (1989) show that the patents of domestic patent owners are of lower value than patents owned by foreigners. Second, I take only renewal costs, not application costs into account as does Putnam (1996). Therefore, the estimated value is a value of the granted patent and not an estimate of the total patent protection. Third, as Warshofsky (1994) notes, a patent must not only be renewed, but it must also be enforced. The costs of enforcement are not included here as is done in Lanjouw (1998) and Deng (2005) and therefore the estimated value is again a lower bound of the real value. Fourth, the patent also has a strategic value that may be correlated with other patents in the patent portfolio of the patentee. Here I assume that the decision to renew a patent is independent, and hence, the strategic value from a patent portfolio is neglected. Fifth, I do not allow for learning as does Pakes (1986) in his stochastic model of patent renewals. Finally, note that the discount rate is set to 10 % for every year even though minimum lending rate of the Bank of Finland was on average 8.6 % between 1971 and 1989. The reason for this simplification is that it makes comparison with previous literature easier.

I find that the average value of Finnish patents is 7 550.5 euros. This is a little lower than estimates of the mean value of other European patents (Schankerman and Pakes 1986, Schankerman 1998, Duguet and Iung 1997, Maurseth 2005, Putnam 1996, Sullivan 1994, Koléda 2005). This may simply be a result of the economy of Finland being smaller than eg that of France.

Table 2: Distribution of the value of patent rights disaggregated by applicant, technology and breadth. The value is expressed in year 2000 euros.

	all	firm	private	che	con	ele	ins
quantile							
0.25	326	499	249	915	466	1 019	223
0.50	1 522	1 584	1 110	5 359	1 518	5 658	671
0.75	5 856	5 673	3 728	25 026	5 572	25 833	2 082
0.90	16 640	13 648	10 175	92 701	15 435	94 149	5 055
0.95	30 889	26 817	18 777	211 193	27 756	205 218	8 135
0.99	91 763	78 780	50 831	976 082	73 645	824 461	20 658
mean	7 550.5	6 606.3	4 469.7	61 459.5	6 562.2	59 100.0	2 985.9

	mec	pro	b0	b1	b2	b3	b4-8
quantile							
0.25	253	287	283	310	311	580	269
0.50	1013	1 280	1 198	1 431	1 309	2 416	1 084
0.75	3 076	4 745	3 831	5 375	4 236	8 554	3 292
0.90	7 677	12 724	10 449	14 686	11 683	25 897	8 220
0.95	12 777	23 181	18 794	27 155	20 682	48 564	14 327
0.99	33 288	67 839	53 209	75 921	53 902	159 570	37 481
mean	3 176.6	5 628.0	4 498.4	6 505.6	4 988.5	12 455.5	3 542.0

che=chemicals and pharmaceuticals, con= consumer goods and civil engineering patents, ele= electrical engineering patents, ins=instruments, mec=mechanical engineering patents, pro=process engineering patents, b0=broadest patents, b4−8=narrowest patents

In accordance with previous research I find that the value distribution of Finnish patents is skewed. Thus, the number of patents is not a good measure for innovation output. Table III depicts an index for the value by renewed years. Patents that are renewed for 10 years are on average more than 80 times more valuable than those patents renewed only for two years. Patents renewed for 20 years are on the other hand almost 25 times more valuable than 10 year old patents. Excluding the first year, I find that renewing a patent for one more year, signals that the patent is worth on average 1.5 times more compared to it not being renewed.

There are factors other than age that affect the value of a patent. There are large differences in values between technologies. Chemical & pharmaceutical (61 459.5 euros) and electrical engineering

(59 100 euros) patents are the most valuable patents, whereas patents on instruments (2 985.9 euros) are the least valuable. This finding is partly in accordance with the results by Deng (2005) and Schankerman (1998), who also report that pharmaceutical and electricity patents are the most valuable. The results are also in line with the results in Levin et al. (1987), Cohen et al. (2000) and Arora et al. (2003), who find that patents are an effective means of protecting chemical and pharmaceutical innovations. My results also coincide with those of Moser (2005), who concludes that secrecy was more effective than patents for innovations on food processing and scientific instruments in the 19th century. The differences between technologies are larger for Finnish patents than for other countries (Schankerman 1998).

Firm patents are 1.5 times more valuable than private patents. This is in line with intuition. Firm patents should be more valuable because firms have more means to innovate and use the patents. Furthermore, private applicants may patent for other than purely economic reasons. The strategic value may also be larger for firms than private persons.

The results are however contradictory to Gambardella et al. (2008), who find that patents of individual innovators are more valuable than those of firms. Gambardella et al. (2008)'s dataset is built from an extensive questionnaire survey where the innovator gives an estimate for the value of the patent. One explanation for the different results may be that individual entrepreneurs tend to be too optimistic. New entrepreneurs overestimate the chances of their business surviving and similarly, individual innovators may be too optimistic when estimating the value of their own patents (Cooper et al. 1988, Pinfold 2001).

The difference between firm and private patents depends on either different characteristics of the innovation or on different characteristics of the innovator. To control for differences in innovation characteristics I estimate the value of patent by technology and breadth conditional on applier to find out whether the result that firm patents are more valuable than private patents holds over all categories. Some samples become very small because there are not many private patents, but the results are conclusive for all categories that could be tested: firm patents are valued as least as much as private patents for all technologies and breadths. The one exception is patents in the technology 'consumer goods and civil engineering' (con). I find that private patents are valued 100 euros more than firm patents in this technology. Thus, the conclusion is that firm patents are more valuable because of the characteristics of the firms, not only because firms patent in different technologies than private persons.

Broader patents are not necessarily more valuable than narrower patents, but also the narrowest patents are not very valuable (Table II). These results show that the assumption of broader patents being more valuable is not consistent with defining breadth as the space between the patented product and the nearest substitute. There may be two factors affecting this result. On the one hand broader patents are of their nature more general and therefore less likely to very valuable. On the other hand, very specific (narrow) patents become obsolete very fast and the time during which one can gain from the patent is short.

Table 3: Value index per renewed year

year	**index**	**year**	**index**	**year**	**index**	**year**	**index**
1	.00004	**6**	.0026	**11**	.018	**16**	.076
2	.00016	**7**	.0041	**12**	.024	**17**	.10
3	.0004	**8**	.0062	**13**	.033	**18**	.12
4	.0008	**9**	.0092	**14**	.044	**19**	.16
5	.0015	**10**	.013	**15**	.057	**20**	.32

5 Conclusion

I estimate the private value of Finnish patents using a deterministic model and cohort level data between 1971 and 1989. I find that the mean value of the patent system is small for most innovations, but substantial for some innovations.

I find that renewing a patent for one more year signals a 1.5 times higher value. But, also other characteristics of the patent and the innovator affect the value. Firm patents are more valuable than private patents. Moreover I find that technologies in which patents are used as the main protection (eg pharmaceuticals), are the technologies in which the value is the highest. I find that breadth, measured as the distance to the nearest substitute, does not, in contrast to assumptions made in theoretical literature, increase the value.

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Essay 2: Why does the private patent value differ by assignee?

Contents

Abstract

I estimate the private value of firms' and individual assignees' patents. I am interested in whether and why there is a difference in private values of different assignees. To investigate this, I use a dynamic stochastic model of patent renewals. I find that firm patents are 60% more valuable than patents applied for by private persons. Estimates from the stochastic renewal model show that this difference comes from firms being better than individual innovators at internalizing revenues from patents. Specifically, firms learn faster and better how to use patents. Individual assignees need to accumulate knowledge for a longer period of time whereas firms can begin sooner to internalize revenues from patents. Moreover, a larger share of firms than private persons learn new ways of using patents and so obtain greater revenue gains from learning.

1 Introduction

According to Schumpeter (1947) 'the inventor produces ideas, the entrepreneur "gets things done" '. This perspective suggests that even though individual innovators can obtain patents, only firms can effectively internalize the revenues from patents. It implies that the private value of patents is higher for firms than for individual innovators. However, there is contradictory evidence on how the private value of patents differs between applicants. Gambardella et al. (2008) found that individual innovators in the PatVal-EU survey[1] report a higher value for their patents than do firms. On the other hand, in essay 1, I find that firm patents are 50% more valuable than patents owned by individuals, and Bessen (2008) reports that large firms have more valuable patents than firms with less than 500 employees in the United States. Finally, Arundel (2001) concludes that small firms are less likely than large firms to find that patents protect product innovation better than does secrecy.

Even though differences have been found between patents owned by firms and individuals, the differences in the private patent value of different owners have not been examined closer (Bessen 2008, Gambardella et al. 2008). It is, however, important to understand whether and how the private value of patents differ between different assignees in order to design an optimal patent policy.

I estimate the private value of patents by patent applicant using a dynamic stochastic model of patent renewals developed by Pakes (1986). Data used are all Finnish patents granted after 1 Jan 1971 but applied for before end 1983. To determine what causes the differences in the private value distribution of firms and individual patents, I examine how patent revenues evolve for firm patents and patents owned by private persons.

The model of Pakes (1986) allows me to investigate how learning to use patents differs between firms and individual patent owners. In this model the patentee is uncertain of future returns from patent protection and experiments every year in order to find new ways to use the patent. If the patent owner learns a new profitable way of using the patent, revenues from the patent protection increase. Each year the patent owner has to pay a renewal fee to keep the patent alive, which he does if current revenues plus the option to continue experimenting and finding new ways of using the patent is worth more

[1] The PatVal surveys 9017 patents granted by the European Patent Office.

than the renewal costs. If he does not pay the renewal fee, the patent lapses forever.

Deng (2007a) uses Pakes' (1986) model to estimate the private value of European patents. The model has been developed further by Lanjouw (1998) who incorporates a potential need to procure infringement. She estimates the private value of patent protection for different technologies. Deng (2005) also estimates the private value of patents for different technologies based on European patents from the 1980s and develops the model further by examining the joint patent application and renewal behavior. The stochastic model of Pakes (1986) has not previously been used to study the difference between private values of patents owned by different assignees.

I find that the private value of firm patents is 60% higher than the private value of patents applied for by individuals. Specifically, individual patent owners need to accumulate knowledge for a longer period of time whereas firms can sooner begin to internalize the revenues from the patent. Moreover, a larger share of firms than private owners learn new ways of using patents and so obtain greater revenue gains from learning. During the first six years, learning is on average 7% higher for firms than for individual patent owners. To sum up, not only are proportionally more firm patents used; they are also used faster and better.

The next section presents the model of Pakes (1986) and outlines the estimation. In section 3, I describe the data. Section 4 is the core section where results on patent value and learning are presented. Section 5 summarizes.

2 Model and Estimation

This section presents the model and outlines the estimation. The model is based on Pakes (1986), but the specifications of the initial distribution follow Lanjouw (1998). The outline of the estimation follows closely the descriptions in Pakes (1986), Lanjouw (1998), Lanjouw (1993) and Deng (2005).

2.1 The model

The patent owner wants to maximize the private value of the patent. The private value of the patent at age t consists of two parts: net revenues in age t, $r_t - c_t$, and the expected value for future periods, $E_t(V_{t+1})$. r_t denotes the revenue from patent protection, and c_t is the yearly renewal fee at age t.

The patentee maximizes the private patent value, V, by deciding when to stop paying the renewal fee. If the patentee decides not to renew the patent, it lapses and cannot be reinforced again. In this case, revenues are zero. Formally the patentee's problem is:

$$max\, V = max[0, \sum_{t=1}^{T} \beta^t E_t(V_t)] = max[0, r_t - c_t + \beta E_t(V_{t+1})], \qquad (1)$$

where β is the discount factor and $t = 1, ..., T$. T is the statutory limit.

The patentee knows the renewal costs, c_t, with certainty. Only revenues, r_t, are stochastic. I specify the revenues in line with Lanjouw (1998). Initial returns, r_0, are zero and r_t follows an exponential distribution. I use Lanjouw's specification because it allows the patent to be applied for at an early stage, before the patentee knows if the patent can be used (this is important for eg pharmaceutical patents).[2]

The return, r_t, depends on three factors: obsolescence, $(1-\theta)$, depreciation, $(1-\delta)$, and learning. The effects of obsolescence are equivalent to radical depreciation. This may be a result eg of a new competing innovation. There is always a probability, $1-\theta$, that the patent becomes obsolete and hence worthless.

If the patent does not become obsolete (with probability θ), the returns develop in one of the two following ways: either the patentee

[2] As Lanjouw (1998) notes, the assumption of patents being homogeneous ex-ante is problematic. We know that there is much heterogeneity between patents even though the applicant is controlled for. Instead of modeling the initial return as zero, it could be a function of patent characteristics.

learns how to use the patent better, or the returns are the depreciated revenues from last year, δr_{t-1}.

Learning can be understood as the firm engaging each year in a project that investigates new ways of using the patent. In some years the project members discover new ways of using the patent, ie the patent owner learns, and in some years the project is unsuccessful. If the project members find a new way of using the patent (learn) the revenues from the patent protection increase. If the project is unsuccessful, the revenues are the depreciated revenues from the previous year.

The yearly project is thus a new level of returns, drawn each year from an exponential distribution

$$q_t(z) = [exp(-((z_t/\sigma_t)+\gamma))/\sigma_t], \ \ z \geq -\gamma\sigma. \tag{2}$$

The parameter σ_t measures the variance of z and is written $\sigma_t = \phi^{t-1}\sigma, \ 0 < \phi < 1$.The variance decreases over time because the patentee starts with the most promising projects. The parameters σ, ϕ and γ together define the exponentially distributed stochastic learning process. The higher the value of σ, the higher the probability that the patentee learns. A high ϕ value means that the potential learning opportunities diminish slowly. A high γ value indicates that the probability of returns staying at zero for some time is high, $\gamma \geq 0$. Thus, a high γ value means that learning takes place some time after the application. If the value of γ is high, the patent owner must accumulate knowledge before being able to internalize revenues from the patent.

The returns from the patent at age t, r_t, are more formally:

$r_t = max(\delta r_{t-1}, z_t)$ with probability θ,

$r_t = 0$ with probability $1-\theta$,

where $1-\delta$ is the constant annual rate of depreciation.

The distribution of next period's returns conditional on current information depends only on known current returns, r_t, and the true parameter vector, ω. The value function to be maximized is therefore

$$V(t, r_t) = max[0, r_t - c_t + \beta E_t(V_{t+1}|r_t, \omega)], \tag{3}$$

where β denotes the real discount rate factor, set at 0.95.
The patent owner renews the patent if

$$r_t - c_t + \beta E_t(V_{t+1}|r_t, \omega) > 0. \tag{4}$$

This means that the revenue needed, $\bar{r_t}$, in order to make it worth-while to renew at time t is

$$\bar{r_t} = c_t - \beta E_t(V_{t+1}|r_t, \omega). \tag{5}$$

$\beta E_t(V_{t+1}|r_t, \omega)$ is the option value of owning the patent and having the possibility of learning how to use it in the future. If the option value is very high, it may be rational to renew the patent even if it has not yet generated any revenue. For example, during the first years, the renewal costs are very low and the option value is high because there are many years during which the owner can learn how to use the patent. Thus, in this model, the revenue requirements may be lower than the renewal costs because of the option value.

2.2 Estimation, estimator properties and convergence

I follow Lanjouw (1998) and Deng (2007a, 2005) and estimate the parameters of the model using a weighted simulated minimum distance estimator.[3] The steps in the estimation are summarized in Table 1.

Table 1: Steps in the estimation procedure

1	Input the renewal fees and hazard rate data.
2	Generate random draws from the exponential distribution using an initial guess of parameters, ω_0.
3	Calculate the threshold value, ie the minimum revenue to make it worth-while to renew, $\bar{r}$.
4	Calculate the simulated hazard rates, λ_t.
5	Choose the parameters that minimize the norm of the distance between the vector of real hazard rates and the simulated hazard rates.

The goal is to find the parameter values that generate simulated hazard rates that are as close as possible to the real hazard rates. To calculate the simulated hazard rates, one needs to compare simulated revenues

[3]Methodologically the patent owner's problem is a control problem where the choice is discrete (whether to renew a patent) and the state variables are autocorrelated. Autocorrelated returns nullify the full solution methods for discrete dynamic processes that assume conditionally independent unobservables and additive separability of the utility function (eg nested fixed point algorithm, conditional choice probabilities and nested pseudo maximum likelihood), but the model could also be solved using Keane and Wolpin (1997)'s algorithm based on simulation and interpolation (Rust 1987, Hotz and Miller 1993, Agguirregabiria and Mira 2002).

with $\bar{r}$, ie the revenues needed to make it economically rational to renew.

Thus, the model is easily solved once we know the threshold value, $\bar{r}$. The threshold value for each age is found by backward induction. In the last period there is no option value for keeping the patent alive, $E_T(V_{T+1}|r_T,\omega) = 0$, and a patent is renewed only if revenues exceed renewal costs, $r_T > c_T$. That is, the threshold value in the last period is the renewal costs, $r_{20} = c_{20}$.

In the period preceding the last, the patent is renewed if revenues and the option value for the last period exceed the costs. The option value for the last period, $E_{T-1}(V_T|r_{T-1},\omega)$, is a function of the revenues in this period, the parameter values, and the threshold value in the last period. Thus, knowing $\bar{r_T}$, we can calculate the option value and the revenues needed to renew in period $T-1$. Having solved the model for period $T-1$, we can continue backwards to the first period.[4]

Once one knows for every year the revenues that make it worthwhile to renew the patent, ie the vector of $\bar{r}$ (step 3 in Table 1), one can calculate the simulated hazard rates. The simulated hazard rates are obtained using the fact that if the simulated revenues are lower than $\bar{r}$, the patent is not renewed. The simulated hazard rates, λ_t, are found using the simulated failure rates, f, and the simulated cumulative distribution of the failures, F:

$$\lambda_t = f_t/(1-F_{t-1}). \tag{6}$$

The failure rates, f_t, are calculated for age t by counting the proportional number of random draws that do not exceed $\bar{r_t}$, and F is the cumulative sum of the proportion of patents failing.

Denote the number of the observations (ie random draws) that survived by n_t. Taking into account obsolescence, the number of patents that would have survived is θn_t and thus the number of patents that would not have survived in the first year is $N - \theta n_1$, where N is the total number of patents. In the second year the number of patents that would have survived after obsolescence is $\theta^2 n_2$, so that the number of patents dropping out in the second year is $\theta n_1 - \theta^2 n_2$. Generally the mortality rates can be written

$$f_t = \theta^{t-1}(n_{t-1} - \theta n)/N_t, \tag{7}$$

[4]See appendix A for details.

and the hazard rate becomes

$$\lambda_t = \frac{\theta^{(t-1)}(n_{t-1} - \theta n)}{N_t * (1-F)_{t-1}}. \tag{8}$$

One must be more careful when calculating hazard rates for the first years in the sample. By the first years in the sample I mean the years where the revenue needed to make it rational to renew the patent, $\bar{r}$, is zero. In these years there are no drop outs except for obsolescence. Thus the mortality rates come from the parameter $\theta : f_t = (1-\theta) * \theta^{(t-1)}$.

Having estimated the simulated hazard rates, the simulated minimum distance estimator, $\hat{\omega_N}$, of the true parameter vector, ω, is chosen to minimize the difference between the population hazard rates, h_N, and the simulated hazard rates λ_N. $\|G_N(\omega)\| = w\|h_N - \lambda_N\|$. w is the weight, $w = diag(\sqrt{n/N})$. This is the same weight used by Deng (2007a) and Lanjouw (1998).

I estimate the model using a two-step numerical optimization strategy, following Lanjouw (1998) and Deng (2005). In this two stage procedure I use both a grid search and a quasi-Newton method, which should be more robust than using just one of the methods. The first step consists of several grid search rounds. In the first round of grid searches, I choose the initial grid points based on previous results from Pakes (1986), Lanjouw (1998), Deng (2005) and Deng (2007). The initial grid points are depicted in Table 2. Thus, I do the steps in Table 1 with all combinations in Table 2 in guesing the initial parameter values, ω_0. This is the first round of grid searches.

Table 2: Initial grid points

δ	0.75	0.80	0.85	0.90	0.95	
θ	0.90	0.92	0.94	0.96	0.98	
γ	0.4	0.5	0.6	0.7	0.8	
σ	100	5 000	9 000	13 000	17 000	
ϕ	0.2	0.3	0.4	0.5	0.6	0.7

From the first round of grid searches I choose the parameters that best fit the data and continue with them to the second round of grid search. The second round of grid search is done in the neighborhood of the optimal parameters from the first round. Now the grids are chosen from a smaller interval.

After a few rounds of grid search, I move to the second step and use a quasi-Newton method to search for the final parameters. The results from the final round are presented in section 4.

For the estimator to fulfill the conditions of consistency and normality it must meet the conditions for identification, uniformity and continuity (Pakes and Pollard 1989, McFadden 1989). Proofs that these conditions hold for this model are found in Lanjouw (1998) and Pakes (1986).

3 Data

The data consist of two parts. The data on patents is from the National Board of Patents and Registration of Finland. It covers all Finnish patents granted after 1 Jan 1971 and applied for before 31 Dec 1983 (5907 patents). The annual renewal costs are from the reports of the Ministry of Trade and Industry. Table 3 summarizes the basic characteristics of the data.

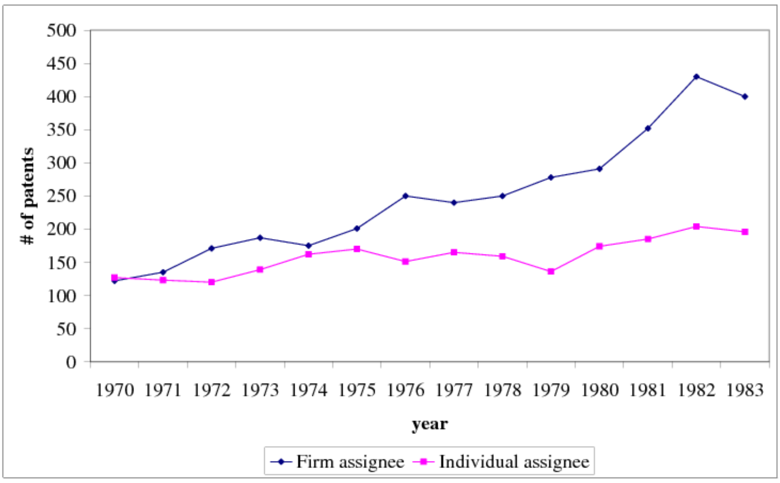
Table 3: Summary statistics

patents studied	granted
number of patents	5907
applied	1970−1983
granted	1971−1993
lag between application and grant	3.3 years
average cohort size	422
average patent length	10.1
percentage firm patents	62%

The average cohort size is 422 patents. There was, however, an increase in grants in 1970−1983. Almost twice as many patents were granted to cohort 1983 (603 patents) as to cohort 1973 (307 patents).

On average, 62 % of the patents are firm patents. But as Figure 1 shows, the relation between firm patents and individual patents has changed over the years. Whereas in 1970 half of the patents were assigned to firms, in 1983 two thirds were firm patents. The change in the relationship between numbers of firm patents and patents owned by individual assignees may be because patents that were previously invented in firms by individuals were more often applied for by the firm than by the individual.

Figure 1: Survival rate of firm and individual assignee patents, 1970−1983



The data cover the renewal history of each patent for the entire patent life. The mean patent length for the complete data is 10.1 years. However, the mean patent length has varied between cohorts such that the lowest average patent length for a cohort is 9.3 and the longest is 10.5 years.[5]

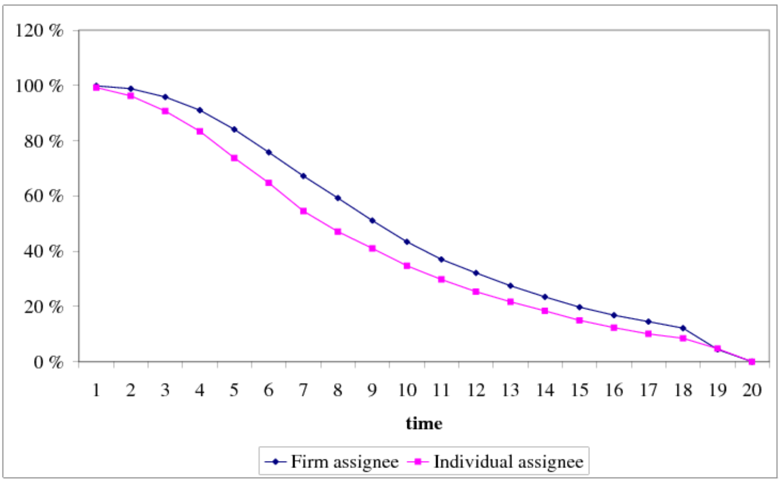
Firm patents are, on average, renewed for a longer time than individual patents. Figure 2 shows that the survival rates are higher for firm patents. This means that there is larger share of firm patents with revenues exceeding renewal costs in every year.

From the patent level renewal history I construct the cohort level hazard rates for private and firm patents respectively. These hazard rates are used in the estimations. As the data consist only of patents that are granted, it is less informative than a survival rate for all patents applied for. As patents cannot lapse before they are granted, there is a possibility that if the granting process has changed over time, this would affect the renewal rates. The grant date is on average three years (3.3 years) after the application date. Some patents were, however, granted in the year of application, whereas some patents had to wait for a decision for as long as 15 years. On average firm patents were granted 3.3 years after application and patents owned by private

[5]The maximum patent life was extended from 17 to 20 years in 1980. This means that every patent in the data set had a statutory life of 20 years. At the time of change, the oldest patents were 11 years. Thus instead of having the option to be renewed for six years, the option was lengthened to nine years. According to non-parametric tests, the longer statutory limit did not affect the renewal rates of patents and therefore the simplification was made that all patents had the option to be renewed for 20 years from the beginning. Essay 4 discusses the non-parametric tests in detail.

persons 3.4 years after application. The standard deviation of the lag between application and grant is 2.04 years for firm patents and 2.05 years for individually owned patents.

Figure 2: Survival rate of firm and individual assignee patents, 1970−1983



The other part of the data used in estimations is renewal fees. Renewal fees are increasing in age. During the first years the renewal fees are less than 50 euros, whereas during the last years they are slightly below 1 000 euros (year 2000 price level). Figure 3 below depicts the renewal fees for patents for cohort 1980.

The technological composition is not uniform across firm patents and patents owned by individual persons (figure 4). Whereas firm patents are distributed more evenly across technologies, only a small fraction of private person patents belong to chemical and pharmaceutical patents, and 37% belong to mechanical engineering patents.

Figure 3: Renewal fees for cohort 1980

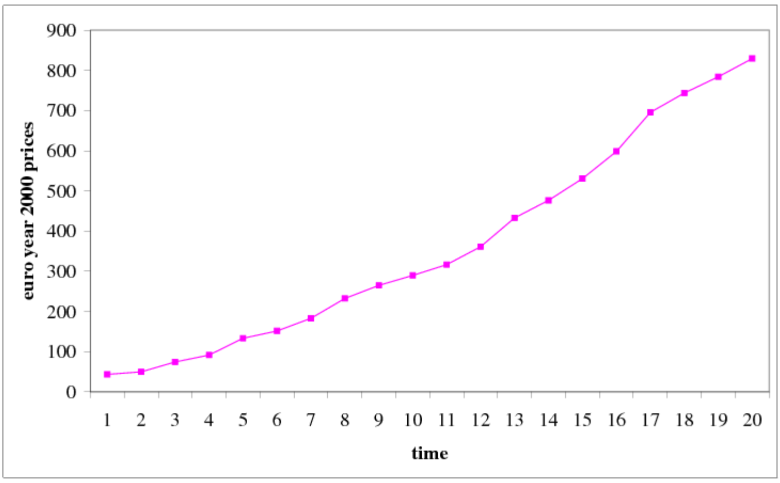
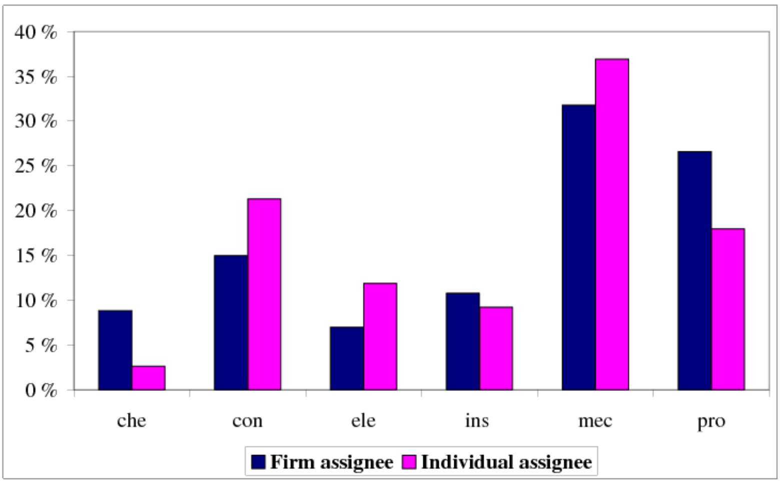


Figure 4: Distribution of firm patents and patents owned by individual assignees by technology



che=chemicals and pharmaceuticals, con=consumer goods and civil engineering, ele=electrical engineering, ins=instrument, mec=mechanical engineering, pro=process engineering

4 Results

In this section I present and discuss the estimated parameter values. Based on the estimates, I then simulate the value distribution. I also estimate how learning differs for patents owned by firms and individuals. Based on the estimated parameters, I calculate the share of patents that generated an increase in revenues.

4.1 Parameters

Part A in Table 4 depicts the estimated parameters, $\hat{\omega}_N$, for firm patents and patents owned by individual persons. The parameter estimates are highly significant. The estimated standard errors, in parenthese, are of the same magnitude as in Pakes (1986).

Part B reports the dimensions. I use 100 simulations per cohort to estimate the parameters. The simulated method of moments is consistent even with only one simulation but more simulations increase the efficiency (McFadden 1989). There are 14 cohorts and, because the maximum life is 20 years, there are altogether 280 cohort-age cells.

Part C reports summary statistics. The mean squared error, MSE, is constructed as the sum of squared residuals divided by the number of cohort-age cells. Var(h) denotes the variance in the real hazard rate. The variance can be thought of as the variance of a naive model, where the hazard rate for each year is predicted by the average hazard rate. The relationship between the mean squared error and the variance is an indicator of how much better the model predicts the real hazard rates than does the naive model.

The parameters predict the hazard rates of firm patents quite well, and the model improves the data fit by 90.8% compared to the naive model (MSE/Var(h) =.092). Moreover, the hazard rates of individual assignees are predicted fairly well. The model improves the data fit by 64% compared to the naive model. Deng (2005) finds that the same model improves the data fit by 46% for pharmaceutical patents and 39% for electronics patents.

Table 4: Parameter estimates*

	firm applicant	individual applicant
A. Parameters		
δ	$0.949(2*10^{-4})$	$0.945(4.2*10^{-3})$
θ	$0.969(2*10^{-4})$	$0.956(4*10^{-3})$
γ	$0.510(1*10^{-4})$	$0.705(2.7*10^{-3})$
σ	1 000(.213)	960(3.904)
ϕ	$0.485(1*10^{-4})$	$0.480(2*10^{-3})$
β*	0.95	0.95
B.Dimension		
# patents	3 663	2 243
# simulations	14*100	14*100
# cohorts	14	14
# cohort-age cells	280	280
C.Summary statistics		
MSE	.0018	.0030
Var(h)	.0195	.0084
MSE/Var(h)	.092	.36

* The real discount factor β is set at 0.95 as in Lanjouw (1998).

The returns decay, δ, at almost the same pace for both firm and individual assignee patents (5.1% and 5.5% per year). This estimate is the same as Lanjouw's (1998) estimate for different technologies. The estimated parameters for obsolescence, 1-θ, (3,1% and 4,4%) are of the same order of magnitude as Deng's (2005) estimates.[6] The estimate for obsolescence in isolation means that 27% of firm patents and 33% of individual patents have become obsolete by the tenth year. Thus, exogenous factors have a significant effect on the turnover of patents. The decay rate and obsolescence together show that technological turnover is fairly rapid and that it is of the same size for Finnish patents as previously estimated for German patents.

The parameters γ, σ and ϕ and together define the learning process. A high γ value indicates that the probability of returns staying at zero is high. Here I find that patents owned by private persons have a higher such probability (0.705) than firm patents (0.510). My estimates correspond to the estimates for textile patents in Lanjouw (1998). The result suggests that Finnish patent applicants, and especially private persons, have had to accumulate much knowledge before being able to use the patent. The estimated parameter

[6]See appendix B for results from Lanjouw (1998) and Deng(2005).

highlights the difference between firms and individual assignees. Whereas firms may have had (tacit) knowledge in the organization of how to internalize the returns from patent protection, the individual applicant had to gather information. A higher γ value may, for example, indicate that the private assignee had to work some time before finding a potential buyer for the patent whereas the firm could start use the patent sooner.

A high σ value indicates that the probability that the patent becomes valuable is high. The estimate for σ is 1 000 for firms and 960 for private person patents. The estimates indicate that the probability that a patent will become very valuable is limited, but larger for firm patents than patents owned by individuals. These estimates are more than four times lower than both Lanjouw's (1998) and Deng's (2005) lowest estimate. Lanjouw (1998) and Deng (2005) estimated the private value of patents in Germany, a much larger country than Finland. The result that these estimates are smaller than previously found corresponds to Deng's (2007b) finding that the private value of patents depends on the size of the economy for the patent protection.

A high ϕ value means that the standard deviation decreases slowly. This means that there is, for a long period of time, a chance that the patent becomes valuable. The estimated ϕ is 0.485 for firms and 0.48 for individually owned patents. This suggests that the possibility that a patent becomes valuable also some years after the application is marginally larger for firm patents than for individually owned patents. These estimates are about the same size as Lanjouw's (1998) estimates.

Figure 5 and 6 show how simulated hazard rates correspond to real hazard rates. Estimated parameters for firm hazard rates generate simulated hazard rates closer to the real hazard rates than the simulated hazard rates for private person patents.

Figure 5: Simulated versus sample hazard rates, firm patents

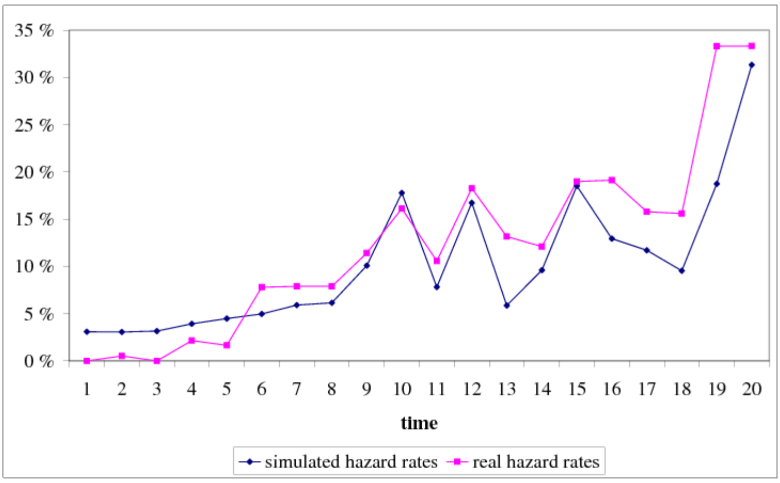
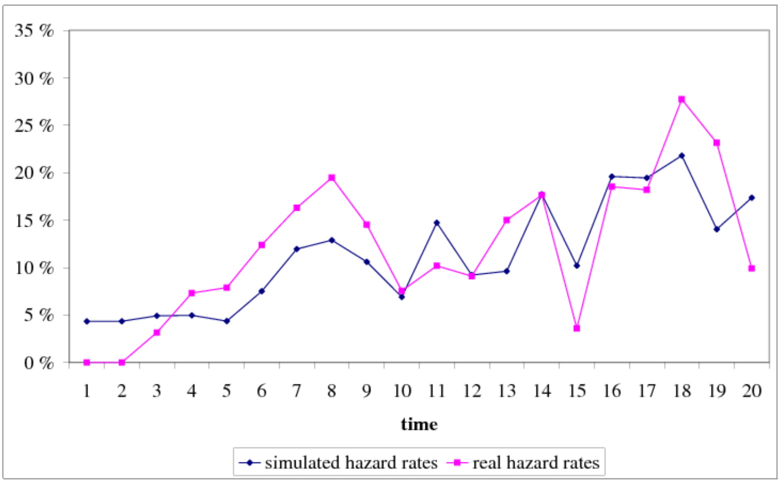


Figure 6: Simulated versus sample hazard rates, patents owned by individuals



4.2 Distribution of the private value of patents

Given the parameter values I can simulate the values of firm patents and patents owned by individuals. The value is the sum of the depreciated returns minus costs. Table 5 depicts the values in year-2000 euros for firm patents and for patents held by individuals. The renewal fees used in the calculations are for patents of cohort 1980.

I find that the mean value of privately owned patents is only 2 330 euros and that the private value of firm patents is 3 709 euro, ie firm patents are 60% more valuable than private person patents. In essay 1, I found that firm patents are 50% more valuable than private patents. The relationship between the value of firms patents and patents owned by individuals is almost the same, regardless of which of the models is used.

Table 5: Distribution of the private value of patents, year-2000 euros*

Percentiles	**firm assignee**	**individual assignee**
50%	1169	0
75%	6 272	4 324
90%	13 930	11 705
95%	19 077	15 837
99%	35 381	27 453
mean	3 708.8	2 329.6

*based on 1 000 simulations

The estimates of the private value of patents are low compared to estimates from larger European countries applied for via the national route. Pakes (1986) estimates the mean value for German patents to be 22 000 (year 2000) euros (16 169 US year-1980 dollars). Lanjouw (1998) also finds that the mean value of textile patents in 1975 was 15 000 (year-2000) euros (17 486 year 1975 DM) and that the mean value of computers was 20 000 (year-2000) euros (23 495 year-1975 DM). Deng (2007b) finds that the size of the country where the patent is granted affects the private value. Thus, it is not surprising that Finnish patents are up to ten times less valuable than German patents.

The estimated mean private value is also lower here than in essay 1. In essay 1 the deterministic model of Schankerman and Pakes (1986) was used to estimate the private value of patents in Finland between 1971 and 1989. The mean value of firm patents was found to be 6 600 euros, and the mean value of individual patents 4 500 euros. To allow for comparison, I have estimated the deterministic model of Schankerman and Pakes (1986) on the data used in this essay. The estimated mean value for firm patents is 10 295 euros and 6 199 euros for patents owned by individuals (Table C1). Thus, this model's estimates are only around 36% of the estimates in the deterministic model. The relationship between the estimates using a deterministic model and a stochastic model are approximately the same as Deng finds for German patents. Deng (2007b) estimates the value of patents in Germany obtained via the EPO route in 1978 to 1996 using a modified version of the deterministic model of Schankerman and Pakes (1986), and Deng (2007a) estimates the private value of German patents obtained via the EPO route in 1980 to 1985 using the stochastic model of Pakes (1986). The estimated mean value using the stochastic model is only 19% of the estimated mean value using the modified deterministic model.

The main reasons for the differences between the deterministic and stochastic models and therefore also in the mean values, are the assumptions on how revenues evolve. In the deterministic model the revenues are declining by definition. However, in this model, returns from the patent protection can increase or decrease. Let us assume for simplicity that we want to estimate the private value of a patent that was renewed for only two years and the renewal fees were 100 euros in the first year and 200 euros in the second year. In the deterministic model, the revenues had to be at least 200 euros in the second year, and the returns from the patent protection had to be more than 200 euros in the first year. However, the returns in the stochastic model (including the option value) had to be at least 100 euros in the first and 200 euros in the second year. Thus the private value of patents will be higher using the deterministic model of Schankerman and Pakes (1986).

The estimated value is the lower bound of the value of a granted patent for many reasons. First, the estimates are based on renewal rates. Hence, the estimated private value is the minimum private value needed for the patent to be renewed. Second, I study only Finnish patents in Finland. Pakes and Simpson (1989) show that the renewal curves of domestic patent owners are significantly lower than those of other patentees. Third, the patent has a strategic value that may be correlated with other patents in the patent portfolio of the patentee. Here I assume that the decision to renew a patent is independent, and hence the strategic value of a patent portfolio is neglected.

4.3 Learning

Innovators apply for patents at an early stage when they are unsure of future returns. After the application, the patentee starts to experiment in order to learn how to use the patent. Experimenting can be thought of as the patent applicant engaging each year in a project that investigates new ways of using the patent. This new information from the project can be knowledge with respect to complementary technology or information about market conditions. In some years the project members discover new ways of using the patent, ie the patent owner learns, and in some years the project is unsuccessful. If the project members find a new way of using the patent the revenues from the patent protection increase. If the project is unsuccessful, the revenues are the depreciated revenues from the previous year (unless the patent becomes obsolete).

Table 6 depicts the implications of the parameter estimates for learning. A patent owner learns if the stochastic revenues, z_t, are higher than the depreciated revenues in the last period, r_{t-1}.

Table 6: Percentage of assignees learning a higher value*

age	firm	individual
1	60.95	50.09
2	36.38	33.53
3	19.61	20.59
4	9.68	11.47
5	4.32	6.37
6	1.95	3.39
7	0.85	1.79
8	0.031	0.82
9	0.001	0.44
10	0.0006	0.24
11	0.0003	.12
12	0.0001	.03
13		.06
14		.01

*based on 15 000 random draws

Learning ends on average by the 12th and the 14th year for firm and individual patent owners respectively. Learning ends later in Finland than in Germany, France and UK (Pakes 1986 and Lanjouw 1998). Table 7 shows, however, that the increase from learning is very small in monetary terms after the 7th year, which is in accordance with previous findings.

Table 7: Average learning in monetary terms (year-2000 euros) *

age	firm	individual
1	984.5	955.8
2	484.1	464.2
3	235.0	219.8
4	111.3	104.0
5	52.3	47.3
6	25.6	23.7
7	11.7	10.7
8	7.1	5.1
9	3.0	2.4
10	.9	1.0
11	.4	.7
12	.5	.2
13		.1
14		.1

*based on 15 000 random draws

In practice, learning ends at the point in time after which the project members do not find any new ways of using the patent. In this model, the parameters that determine when learning ends are ϕ and γ. If ϕ is large, the variance of the yearly new return decreases slowly and the innovator learns, after many years, new ways to use the patent, ie there is, after many years, a positive probability that the patent becomes valuable. If γ is large, the innovator has to accumulate knowledge before the patent can be used economically. Consequently learning takes place later in time.

The obsolescence rate $(1-\theta)$ and the depreciation rate $(1-\delta)$ also have (indirect) effects on learning. Once the patent becomes obsolete, there cannot be any learning. If the depreciation rate of revenues is high, there is a higher probability that the innovator will find a new and more profitable way to use the patent.

There are three differences between how firms and individuals learn new ways to use a patent. First, firms learn to use the patents faster than do individual patent owners. It is especially interesting that more firms learn to use the patent during the first two years because after 18 months patent applications become public. Thus, after new information is revealed to other companies, learning is no longer very fast.

Second, firm patents more often generate increasing returns. Summing the percentages in table 6, we see that there is more often learning for firm patents than for patents applied for by individuals (134% versus 129%).

Third, firms' learning is, in most year, greater in monetary terms than that of individual patent owners' learning (Table 7). The conclusion is that a larger share of firms can internalize the revenues from patents. To sum up, firms can internalize the revenues of patents faster and to a larger extent than can individual innovators.

4.4 Discussion

The findings above indicate that firms internalize revenues from patents more effectively than individual patent owners. This is in accordance with Schumpeter (1947)'s idea that even though individuals can invent, firms are better at transforming the invention to an innovation that has economic value. It is also consistent with empirical results. Mansfield et al. (1977) find that the probability that an independent inventor succeeds in commercializing an invention is much lower than that for a firm. Braunerhjelm and Svensson (2007) investigate the commercialization of patents and find that commercialization is weak when the inventor commercializes his patents in his own firm. The conclusion is that large firms probably are better at commercializing patents because they have networks and routines to do this.

There are many reasons, in addition to learning, why firms should be better at internalizing revenues from the patent protection. Although these reasons cannot be tested using this model, I will discuss them briefly in the next subsection. The second subsection summarizes the policy conclusion of this paper.

4.4.1 Explanations for the discrepancy in the private value of patents

There are many potential reasons for the difference in the private value of patents that are not addressed in this paper. First, there may be asymmetries in the ability to obtain external financing between firms and individuals. Gambardella et al. (2007) find that many patent owners left their patents unused because of a lack of resources. The data used in this paper does not allow one to examine if this is the case. To find out whether financial constraints matter financial data should be combined with renewal data. This is done in essay 3.

Second, firms should be better at internalizing revenues, as they have technological complementaries (Arrow 1962). Thus, if an individual gets a patent on an innovation that is not the core competence of his small firm, the patent may not be used. The problem of a lack of technical competence is alleviated if there is no well functioning market for patents that allows innovators to license and sell their patents or to form patent pools (Bessen 2008). To be more specific, all patent owners benefit from a well functioning market for patents, but there is empirical evidence that suggests that small firms or individuals benefit more from a market for technologies than larger firms. Based on data from larger European countries between 1993 and 1998, Gambardella et al. (2007) conclude that licensed patents are owned by smaller firms. Also Serrano (2008) finds that individual innovators and small innovators most actively sell their patents. Thus, when it is possible to license or sell patents, small firms and individuals are more inclined than large firms to do so. This model does not allow one to investigate how technological complementaries affect the private value of a patent. To do that, the model had to be extended so that patents are not dependent on the whole patent portfolio of the patent owner.

Third, a patent must not only be renewed; it must also be enforced (Warshofsky 1994). Arundel (2001) reports that small firms may find it hard to protect their patents from infringements and so are not able to internalize the revenues from the patent protection. Arora et al. (2008) find that larger firms have a higher patent premium and conclude that it is consistent with larger firms having better access to legal resources. To examine whether the ability to enforce is important, one could use the extended model of Lanjouw (1998) with data on litigation.

Fourth, there may be differences among innovators that produce the underlying innovations. If firms are better at internalizing revenues, they can pay researchers more than can a private innovator and so they can attract the best innovators. Already Schmookler (1957) asked '(W)who engages in an inventive activity, why, when, and how?' and these questions are relevant also for understanding the differences between firm and private person patents.

Fifth, there may be differences in the underlying innovations. Winter (1984) predicted that there are differences in innovation between small and large firms. Acs and Audretsch (1988) indeed found some evidence that different economic and technological factors affect the innovation of firms of different size.[7]

Related to this is the argument that the private value of patents may differ because firms and individual persons have patents in different technologies. Figure 4 shows that firms and individually owned patent in different technologies and therefore the discrepancy in value may be due to the technological composition. However, as Essay 1 shows, firm patents are more valuable than individually owned patents in all technologies. When one multiplies the shares of firm and private person patents in each technology by the mean values obtained in Essay 1, one finds that that firm patents are 5% more valuable that individually owned patents.[8] This implies that only a small fraction of the difference between firm patents and patents owned by private persons can be explained by the fact that firms and private persons patent in different technologies.

As figure 1 shows, the share of firm patents has increased over time. If patents for some exogenous reason became more valuable in the 1980s than in the 1970s, the conclusion that firm patents are more valuable than patents owned by private persons may be endogenous. But, when I estimated the private value of patents using the deterministic model of Schankerman and Pakes on patents from

[7]There may also be differences in patented innovation because firms are risk neutral whereas private persons are risk averse. Or, even if also individual patent owners are risk neutral, only firms are able to act as their own insurance company because they have many patents (Arrow 1962). Moreover, firms have other motives than private persons to patent. Cohen et al. (2000) argue that firms patent mostly for strategic reasons and Svensson (2003) finds evidence for this for Swedish patents. Individuals, on the other hand, may be driven by other motives than purely economic ones and therefore their patents may be of lower economic value. Rossman (1931) finds, having interviewed individual patent owners with many patents, that individuals' primary motives for innovating are love of inventing and desire to improve. Cooper et al. (1988) and Pinfold (2001) show that new entrepreneurs overestimate the chances of their business surviving and similarly, individual innovators may be too optimistic when estimating the value of their own patents. Toivanen and Väänänen (2008) state that owning a patent may be a signal of the person's ability and productivity.

[8]Mean value of patents from essay 1: che 61 550 EUR, con 6 562 EUR, ele 59 100 EUR, ins 2 986 EUR, mec 3 177 EUR, pro 5 628 EUR. When multiplying these values with shares in figure 4 the mean value is 13 360 euros for firm patents and 12 771 euros for individually owned patents.

cohorts 1971−1989, I found that they were less valuable than patents applied for before 1984. Thus, it seems that the private value of patents did not increase during the 1970s and 1980s, so this would not explain the difference between firm and individual assignee patents.

4.4.2 Policy implications

One reason for having a patent system is that patents increase incentives to innovate through increased internalization of returns from innovations. If the internalization of patent revenues is difficult for individual assignees (and maybe small firms), this means that the patent system fails at providing incentives to innovate.

If patents are seen as a good incentive mechanism for innovation, there are two policy tools that could improve the internalization of patent revenues, at least for individuals and small firms. First, technological policy can be formed to support not only product development but also commercialization. I find that private assignees have to gather more information before they learn how to use patents. If this phase can be shortened, the private value of patents would increase, and this should increase the incentiv to innovate. The result that individual innovators did not internalize their revenues later than firms in the 1970s in Finland, may depend on the fact that the technology policy of the 1970s mostly supported industrial research (Murto et al. 2007, page 137).

Second, if patent owners do not learn to use patents, this means that the diffusion of the new technology may also be ineffective. Promoting a well functioning patent market that makes it possible for patent holders to license and sell patents or to form patent pools more effectively could improve the diffusion of new technology. Even though the worldwide patent market has developed since the 1970s and early 1980s, the possibility to commercialize a patent can still be made easier, especially for individual innovators and small firms.[9] For example, the licensing system in most countries today favors large players, and patent pools are designed mainly for large companies (Jaffe and Lerner 2004, Detkin 2007).

[9] In the United States IP investment banks such as Think Fire and ipValue Management help their clients evaluate and make profit on their patents. There are also companies that buy patents and licence patents further and companies that assemble patent portfolios from different patent owners and license or sell whole portfolios. Patent auctions are held in US, Europe as well as Taiwan. And Ocean Tomo, the creator of patent auction, also works on creating an intellectual property exchange (http://www.ipxchicago.com/). (Detkin 2007)

5 Conclusion

This paper estimates the private value of Finnish patents using a dynamic stochastic model. I focus on the difference between firm assignee and individual assignee patents and especially on how learning differs across applicants.

There is a substantial difference in the private value distribution between patents owned by firms and individual persons: the private value is 60% higher for firm assignees than individual assignees. Thus, this study shows that the probability of patents becoming valuable is conditional on the applicant and this should be accounted for in research using patents as proxies for innovation.

The discrepancy in the private value of patents between firms and individual assignees is due to firms being better at learning. Specifically, individual patent owners have to accumulate knowledge for a longer period of time whereas firms can start internalizing the revenues from a patent sooner. Also, a larger share of firms than private owners learn new ways of using a patent, and the increase in revenues due to learning is also higher for firms.

The results indicate that if patents are used as an incentive mechanism, the incentives can be made larger by supporting faster use of patents for individual assignees (small firms). I therefore suggest that the commercialization of patented innovations and measures toward a market for patents should be supported.

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A How to calculate the $\bar{r}$ vector.

Appendix A is based on the solution algorithm developed in Pakes (1986) and Lanjouw (1998).

To estimate the value, it is necessary to know the minimal revenues in each age t that makes it worthwhile to renew the patent,

$$\bar{r_t} = c_t - E_t(V_{t+1}|r_{t,}\omega). \tag{A1}$$

Thus, to know $\bar{r_t}$ the expected value for t+1 has to be known. The $\bar{r}$ vector, is solved by starting with the last period and then solving it recursively using numerical integration.

There is no option in the last period, $E_{20}(V_{21}|r_{20,}\omega) = 0$, and therefore $\bar{r}_{20} = c_{20}$. The option value for t=20, $E_{19}(V_{20}|r_{19}, \omega)$, depends on the realization of z in period 20 and on δr_{19}. If $\delta r_{19} \leq \bar{r}_{20}$, the expected value depends on whether the patentee learns a new way to use the patent, ie on the stochastic part of the return, z. If $\delta r_{19} > \bar{r}_{20}$, the expected value depends on the stochastic outcome as well as on the depreciated revenue from age 19. Analytically:

i) if $\delta r_{19} \leq \bar{r}_{20}$

$$E_{19}(V_{20}|r_{19}, \omega) = \int_{\bar{r}_{20}}^{\infty} (z_{20} - c_{20}) dQ_{20}(z) = h_{19}^{0}. \tag{A2}$$

ii) if $\delta r_{19} > \bar{r}_{20}$

$$E_{19}(V_{20}|r_{19}, \omega) = \int_{-\gamma\sigma_{20}}^{\delta r_{19}} (\delta r_{19} - c_{20}) dQ_{20}(z) +$$

$$\int_{\delta r_{19}}^{\infty} (z_{20} - c_{20}) dQ_{20}(z) = h_{19}^{0} + h_{19}^{1}. \tag{A3}$$

The option value for t=19, $E_{18}(V_{19}|r_{18}, \omega)$ depends accordingly on the realization of z in period 19 and the depreciated revenue from period 18, δr_{18}. If $\delta r_{18} \leq \bar{r}_{19} \leq \bar{r}_{20}/\delta$, the expected value depends on whether the patentee learns a new fruitful way of using the patent in period nineteen and in the last period. If $\bar{r}_{19} \leq \delta r_{18} \leq \bar{r}_{20}/\delta$, the expected value depends on the depreciated revenue and the stochastic outcome in period 19 plus the stochastic outcome in period 20. If $\delta^2 r_{18} > \bar{r}_{20}$, the expected value depends on the depreciated revenue from period 18 in all future periods and the stochastic outcome in all future periods. Analytically:

i) if $\delta r_{18} \leq \bar{r}_{19}$

$$E_{18}(V_{19}|r_{18},\omega) = \int_{\bar{r}19}^{\infty} (z_{19} - c_{19}) dQ_{19}(z) + \int_{\bar{r}19}^{\bar{r}20/\delta} (\beta\theta h^0_{19}) dQ_{19}(z)$$

$$+ \int_{\bar{r}20/\delta}^{\infty} (\beta\theta(h^0 + h^1)(z)_{19} dQ_{19}(z) = h^0_{18}. \qquad \text{(A4)}$$

ii) if $\bar{r}_{19} \leq \delta r_{18} \leq \bar{r}_{20}/\delta$

$$E_{18}(V_{19}|r_{18},\omega) = \int_{-\gamma\sigma_{19}}^{\delta r_{18}} (\delta r_{18} - c_{19} + \beta\theta h^0_{19}(\delta r_{18})) dQ_{19}$$

$$+ \int_{\delta r_{18}}^{\bar{r}20/\delta} (z_{19} - c_{19} + \beta\theta h^0_{19}(z)) dQ_{19}$$

$$+ \int_{\bar{r}20/\delta}^{\infty} (z_{19} - c_{19} + \beta\theta(h^0 + h^1)(z)_{19} dQ_{19}(z) = h^0_{18} + h^1_{18}. \qquad \text{(A5)}$$

iii) if $\delta^2 r_{18} > \bar{r}_{20}$

$$E_{18}(V_{19}|r_{18},\omega) = \int_{-\gamma\sigma_{19}}^{\delta r_{18}} (\delta r_{18} - c_{19} + \beta\theta(h^0_{19} + h^1_{19})) dQ_{19}$$

$$+ \int_{\delta r_{18}}^{\infty} (z_{19} - c_{19} + \beta\theta(h^0_{19} + h^1_{19})) dQ_{19} = h^0_{18} + h^1_{18} + h^2_{18}. \qquad \text{(A6)}$$

h^0_t is the expected value in t+1 when $\delta r_t \leq \bar{r}_{t+1}$. h^0_t is composed of two parts: the stochastic outcome in period $t+1$ and the possible stochastic outcomes in future years. Thus h^0_t is completely independent of the revenues at age t since h^0_t is only composed of the stochastic element. Analytically:

$$h_t^0 =$$

$$\int_{\overline{r}_{t+1}}^{\infty} (z_{t+1} - c_{t+1}) dQ_{t+1}(z) + \beta\theta \sum_{v=0}^{20-(t+1)} \int_{\overline{r}_{t+v+1/\delta^v}}^{\infty} h(z)_{t+1}^{v} dQ_{t+1}(z). \tag{A7}$$

h_t^1 is the incremental increase to h_t^0 if the depreciated revenue of year t, δr_t is larger than $\overline{r}_{t+1}$. That is it is the incremental increase that arises due to the fact that the expected value of the patent depends not only on the stochastic element, but the depreciated revenues are actually larger than the revenues needed to renew the patent. Analytically

$$h_t^1 =$$

$$[Q_{t+1}(\overline{r}_{t+1})] * [\delta r_t - c_{t+1} + \beta\theta(h_{t+1}^0)] + \beta\theta \int_{\overline{r}_{t+1}}^{\delta r_t} [\delta r_t - z_{t+1}] dQ(z)_{t+1}. \tag{A8}$$

h_t^v,v>1, is the incremental increase when $\delta^v r_t > \overline{r}_{t+v}$. This is the increase that arises since the certain revenues are so large that the depreciated returns from year t will be larger than the renewal costs in $t+v$. Analytically:

$$h_t^v = [Q_{t+1}(\overline{r}_{t+v}/\delta^{v-1})] * [\beta\theta h_{t+1}^{v-1}(\delta r_t)]$$
$$+\beta\theta \int_{\overline{r}_{t+v}/\delta^{v-1}}^{\delta r_t} [h_{t+1}^{v-1}(\delta r_t) - h_{t+1}^{v-1}(z)] dQ(z)_{t+1}. \tag{A9}$$

B Parameter estimates from Lanjouw (1998) and Deng (2005)

Table B1: Lanjouw (1998)

	computers	**textiles**	**engines**	**pharmaceuticals**
δ	0.95	0.96	0.94	0.94
θ	0.93	0.92	0.88	0.90
γ	0.27	0.53	0.07	0.00
σ	4 942	4 087	9 534	13 111
ϕ	0.48	0.57	0.60	0.31
β	0.95	0.95	0.95	0.95

Table B2: Deng (2005)

	Germany	**France**	**U.K**
δ	0.92	0.92	0.90
θ	0.95	0.97	0.95
γ	0.15	0.41	0.20
σ	9 980	4 930	6 999
ϕ	0.60	0.62	0.60
β	0.95	0.95	0.95

C Value distribution using the Schankerman and Pakes (1986) model

Table C1: Distribution of value using the Schankerman and Pakes (1986) model. Amounts expressed in year-2000 euros.*

Percentiles	firm patents 1970−1983	individually owned patents 1970−1983
50%	2 583	1 418
75%	8 801	4 813
90%	23 174	13 885
95%	41 792	24 952
99%	115 440	73 389
mean	10 295	6 199

*based on 50 000 simulations

Essay 3: Do the assignee's characteristics affect the private value of patents?

Contents

Abstract

I assess the effect of firms' characteristics on the private value of its patents. Specifically, I study whether there is a relationship between the private value of patents and the variables found to have an effect on innovation, ie firm size, average wage, leverage and profitability. I find that firm size has a negative effect on the private value of patents whereas firms paying higher average wage have more valuable patents. Results also indicate that there are imperfections in financial markets. Small firms with higher leverage costs have patents of lower value whereas more profitable firms have more valuable patents. Thus, it seems that firms have to use internal financing to appropriate revenues from patents.

1 Introduction

Markets do not produce the optimal level of innovations because of increasing returns, inappropriability, and uncertainty in research and development projects (Arrow 1962). Intellectual property rights and specifically patents are granted to innovators to increase the internalization of research and development investments. The received protection and conditions for renewal are the same for all firms, regardless of size, market power or industry.[1] But, in March 2004 the European Commission decided that Microsoft must share information about its products to competitors and so, based on abuse of market power, the European Commission decreased Microsoft's intellectual property protection.[2] If the rendency is toward firm-specific intellectual property rights, more knowledge will be needed on how the strength of intellectual property rights depends on the characteristics of the patent holder.

In this paper I estimate how the private value of patents depends on characteristics of the assignee. Specifically, I estimate whether factors found to affect innovation also affect the private value of patents. Theoretical and empirical work on determinants of innovation stress the effect of eg firm's size, financial resources, human capital and market structure on innovation (eg Schumpeter 1911, 1942, Scherer 1992, Cohen 1995, Hall 2002, Lerner 2006, Nelson and Phelbs 1966, Varsakelis 2006). Here I examine closer the relationship between assignee characteristics − size, leverage costs, profitability and human capital − and the private value of patents. I also control for patent technology and breadth.

In practice, the private value of patents is high only if someone else uses the patents. That is, firms that should benefit from renewing a patent rather than letting it lapse are those that are able to sell or license the patent, enforce the patent or use it strategically. It is therefore not intuitive that factors affecting innovation would also affect the private value of patents. However, we have very little information on the determinants of the private value of patents, and a starting point for gaining insight is to investigate the factors that have been found to have an impact on innovation.

In estimating the private value of Finnish patents I assume that a patent is renewed as long as revenues from the patent exceed

[1] The statutory limit is 20 years in Finland. All patent owners pay the same renewal fees. The scope of the patent depends on the characteristics of the innovation, not the patent owner.

[2] http://ec.europa.eu/comm/competition/antitrust/cases/microsoft/

the yearly renewal fees. Renewal rates and fees were first used by Schankerman and Pakes (1986) to estimate the private value of patents. The intuition is that a patent owner does not renew his patent if revenues from the patent are less than yearly renewal costs. In this model, the assumption is that the patent owner knows with certainty the revenues from patent protection. Here I extend Schankerman and Pakes's (1986) model by assuming that there is a yearly shock to the patent revenues. This means that the patent owner does not know with certainty at the start of the patent life what the future revenues will be. This extension brings the model closer to reality because the patent owner has to make a new decision every year, as he does not know how revenues will evolve. The extension also allows me to eg investigate how the decay rate of patent revenues changes over the life of the patent. However, this extension does not assume that the patent owner is forward looking or that the yearly shocks are autocorrelated, as in Pakes (1986).

The private value of patents has previously been shown to differ by technology, nationality of the inventor, designated country of patent protection, type of the patent, type of owner, and patent family (Schankerman and Pakes 1986, Schankerman 1998, Deng 2007a, Deng 2007b, Koléda 2005, Fikkert and Luthria 2000, essay 1, essay 2).

This paper, however, relates most closely to Bessen (2008), who estimates the impact of patent and owner characteristics on the private value of US patents. He estimates the Schankerman and Pakes (1986) model using patent level data from 1985 to 1991. Bessen (2008) finds that patents owned by individuals, small companies, and non-profit organizations are less valuable than patents owned by large entities. Moreover new firms have patents of lower value than old firms. Using a subset of patents owned by publicly listed US manufacturing firms, Bessen (2008) finds that patent value increases with firms' research and development spending. Also Deng (2007b) estimates the private value of patents using a modified version of the deterministic model of Schankerman and Pakes (1986). She finds eg that the private value of patents increases with the size of the country in which the patent is sought.

This paper is also related to Arora et al. (2008). They estimate the patent premium, and examine how firm characteristics affect the incremental value of an innovation that is realized when it is patented. They find that the size of the firm, the business unit size, the legal form, and having a presence in many countries affect the patent premium.

I find that profitability is positively correlated with the private value of patents. This suggests that firms use internal resources to internalize revenues from patent protection. Leverage costs have a negative impact on the private value of patents in smaller firms. Thus, smaller firms seem to be financially constrained to internalise the whole revenue from the patent protection. These two results suggest that imperfections in financial markets hinder not only innovation but also the internalization of returns from patent protection. It seems that risks related to commercialization are substantial and may decrease incentives to innovate. Therefore technology policy should not only support the R&D stage, but also the commercialization of new products.

I also find that firm size correlates negatively with the private value of patents. Thus, this result suggests that, having controlled for financial characteristics, the internalization of patent protection is the weaker, the larger the organization.

The last finding is that firms with higher average wage expenses have more valuable patents. This result holds for all firms and suggests that a more educated workforce not only innovates more, but is also better able to internalize revenues from (at least) those innovations that are patented.

This paper is structured as follows. Section 2 presents the model and the estimation. Section 3 describes the data. In section 4, I present the results, and section 5 concludes.

2 The Model and the Estimation

The model of Schankerman and Pakes (1986) is the starting point for the model estimated in this paper. The patent owner wants to maximize the private value of patent i, V_i:

$$max_{t^* \in [1,2,....T]} V_i = \sum_{t=1}^{T} \beta^t (R_{it} - C_t), \tag{1}$$

where C_t is yearly renewal fee at time t. R_{it} is the return on patent i at time t, and β denotes the discount factor. T is the maximum age of patents (20 years).

The patent owner maximizes the private value of the patent in deciding for how many years he will renew the patent. If the patent is not renewed, the value of the patent is zero. Hence, the patent owner keeps the patent if revenues from the patent exceed the yearly renewal costs, $R_{it} > C_t$. A patent that has lapsed cannot be reinforced again.

I model revenues, R_{it}, as a function of initial revenues, R_{i0}, a decay rate of the initial revenues, δ_{it}, and, as an addition to the original model of Schankerman and Pakes (1986), a yearly shock, ε_{it}

$$R_{it} = [R_{i0} \prod_{t=2}^{t} (1 - \delta_{it})] exp(\varepsilon_{it}). \tag{2}$$

The reason for introducing the yearly shock, ε_{it}, is that in practice the renewal decision is sequential, ie the patent owner renews the patent in year t given that it was renewed in year $t-1$. In the original model of Schankerman and Pakes (1986), however, the renewal decision is not sequential. In that model the patent owner knows when applying for the patent the initial return, R_{i0}, the decay rate, δ_{it}, and the renewal costs for all years. Thus in the Schankerman and Pakes (1986) model the patent owner knows, when applying for the patent, everything about the revenues and the costs and can decide for how many years the patent is to be renewed. In my model, however, the patent owner does not know the yearly shocks, ε_{it}, and therefore does not know, when applying for the patent, for how many years he will renew the patent. Instead, he has to make a renewal decision at the start of each year, when the yearly shock is realized. This is the difference between the model estimated here and the model of Schankerman and Pakes (1986).

The difference between this model and the dynamic stochastic model of Pakes (1986) is that the patent owner is here not forward looking. That is, if revenues in year t are less than costs, the patent is not renewed. Future revenues, ie the option value, is not taken into account.

2.1 Specification

2.1.1 Initial return

The revenues from the patent protection tell us how much renewing the patent increases the internalization of the returns from the innovation compared to the situation where the patent has not been renewed. The initial revenues may depend on the underlying technology. That is, if it is a good innovation, which substantially decreases the costs of production, the patent should be valuable to the owner. The revenues may also depend on the industry. For example, in some industries standard setting is more important than in others. Patents related to the main standard may not be very valuable to the patent owner in these industries. Furthermore, the patent revenues may be dependent on the characteristics of the patent owner. For example, for firms that find the enforcement of patents difficult, revenues from a patent may not be very high. Thus, the initial return, R_{i0}, depends not only on patent and industry characteristics, but also on patent-owner characteristics.

The initial return, R_{i0}, is a random variable that is independently and identically distributed (i.i.d) over patents. This means that there is no correlation between patents of the same patent owner. Nor is there any correlation between patents from the same cohort. The assumption of i.i.d distributed patents is strong, because it assumes eg that two patents owned by the same firm and protecting the same innovation are not correlated even though they come from the same research and development project. However, the assumption of independent patents is common in all models that employ renewal rates and fees to estimate the private value of patents (eg Schankerman and Pakes 1986, Pakes 1986).

The log of initial returns is normally distributed with mean μ_r and standard deviation σ_r: $r_{i0} = ln(R_{i0}) \sim \mathrm{N}(\ \mu_r\ ,\ \sigma_r)$.[3] Because I am interested in how characteristics of the patent owner affect the private patent value, I assume that the initial distribution is a function of characteristics of the assignee and characteristics of the patent.

[3]See appendix for previous research on the private value using the deterministic model of Schankerman and Pakes (1986). Almost all previous studies have used the log normal distribution (Table A2).

2.1.2 Decay rate

The decay rate, δ_{it}, is the pace at which the initial revenues, R_{i0}, diminish every year, $\delta_{it} < 1$. It is a measure of technical turnover. The decay rate may therefore hinge not only on characteristics of the innovation but also on characteristics of the industry and market structure.

Here the decay rate is assumed to be exogenous and equal across patents, $\delta_{it} = \delta_t$. It, however, need not have to be constant throughout the patent life.

2.1.3 The yearly shock

The yearly shock, ε_{it}, is interpreted as a shock to patent protection. It is the outcome of external things from the patent owner's perspective. Thus, the yearly shock is not affected by characteristics of the patent owner, the patent, or patent age.

The yearly shock, ε_{it}, is independently and identically distributed over patents and time. The assumption of an independently and identically distributed shock over time and patents is stringent. It means that exogenous factors, such as competitors' behavior, are not correlated over patents. The shock is normally distributed with mean zero and standard deviation $\sigma_\varepsilon : \varepsilon_{it} \sim N(0, \sigma_\varepsilon)$.

2.2 Timing and the renewal decision

The timing is as follows: The patent owner applies for patent i at the start of year 1. At application he learns the initial revenue distribution of the patent, R_{i0}. At the same time, the shock for the first year, ε_{i1}, is realized. The patent owner renews the patent in year 1 if revenues exceed costs, $R_{i1} = R_{i0} exp(\varepsilon_{i1}) > C_1$. At the start of year 2 there is a new yearly shock, ε_{i2} and revenues from the patent protection are $R_{i2} = [R_{i0} * (1 - \delta_2)] exp(\varepsilon_{i2})$. Again, the patent is renewed if revenues exced costs, $R_{i2} > C_2$.

Assume, for simplicity, that the decay rate is constant over the whole patent life, $\delta_t = \delta$. Then the patent is renewed if

$$r_{i0} + (t-1) * ln(1-\delta) - ln(C_t) + \varepsilon_{it} > 0, \tag{3}$$

where r_{i0} is the log of initial returns. The renewal costs, C_t, are increasing in age and the deterministic part of revenues, $r_{i0} + (t-1) * ln(1-\delta)$, are decreasing. As the patent owner is myopic, the renewal decision may be sub-optimal. The renewal decision is optimal if the differences in two subsequent yearly shocks is not too large. If the yearly shock, ε, gets a large negative value in one year and a large positive value in the subsequent year, there is a theoretical possibility that the decision not to renew the patent is sub-optimal.

2.3 Likelihood and Estimation

The probability that eg the patent is renewed for three years, ie $t^* = 3$, is conditional on the patent having been renewed also for the first two years:

$$Pr[t = t^*] = Pr[t = t^*|t > (t^* - 1)] * Pr[t > (t^* - 1)]. \tag{4}$$

Thus, the likelihood for an individual patent *i*, $Pr[t = t^*]$, is

$$L_i = h_{it^*} * \prod_{t=1}^{t^*-1} [1 - h_{it}] \tag{5}$$

where h is the hazard rate.[4] Setting the indicator y at 1 in periods where the patent was renewed and 0 when it was not renewed, the log likelihood (l_i) of a representative patent becomes

$$l_i = (1 - y_{it^*}) * ln(h_{it^*}) + \sum_{t=1}^{t^*-1} y_{it} * ln(1 - h_{it}) \tag{6}$$

and the total log likelihood is the sum over all patents. This is the random effect probit likelihood because

$$h_{it} = F(\frac{-r_{i0} - (t-1) * ln(1-\delta) + ln(C_t)}{\sigma_\varepsilon}). \tag{7}$$

F denotes the standardized normal cumulative distribution function and r_{i0} is a random variable with mean μ_r and standard deviation σ_r. r_{i0} can be written as the sum of two random variables, μ+ a, where μ

4

$$Pr[t > (t^* - 1)] = \prod_{r=1}^{t^*-1} \{1 - Pr[t = r|t > (r-1)]\}$$

and

$$Pr[t = t^*|t > (t^* - 1)] = h_{it}$$

is a random variable with mean μ_r and standard deviation zero and a is a random variable with mean zero and standard deviation σ_r. The probability of not renewing a patent, conditional on a and μ, is

$$h_{it} = P(y_{it} = 0|a, \mu_r) = F(\frac{-\mu - a_i - (t-1) * ln(1-\delta) + ln(C_t)}{\sigma_\varepsilon}) \tag{8}$$

ie $y_{i1}, ..., y_{iT}$ are independent and conditional on μ and a (Wooldridge 2002). I estimate the parameters using the Gaussian quadrature procedure, as in Butler and Moffitt (1982), but one could also use simulation, stochastic integration, or a two stage procedure suggested by Borjas and Sueyoshi (1993) (Train 2003).

3 Data

3.1 Construction of the sample

The data is built up from three sources. Data on all granted Finnish patents in Finland are from the National Board of Patents and Registration of Finland. These data were merged with financial statement statistics from Statistics Finland. The third building block of the data set was the annual renewal costs, from reports of the Ministry of Trade and Industry.

In 1990 the renewal fees were changed so that the cost schedule is no longer increasing in age. Therefore only patents applied for before 1990 are used. But the financial statements statistics starts in 1986 and consequently only patents applied for in 1986−1989 are used. There were 3109 granted Finnish patents from cohorts 1986 to 1989. But the financial statements cover only companies with at least 100 employees and therefore all patents owned by small companies and individuals are excluded. Thus, the merged data set contains only 2458 patents.

All patent owner characteristics are measured one year before the patent application was made. The reason for this is twofold. First, the initial distribution of patents should at least to some extent depend on the characteristics of the underlying innovation. Therefore I measure innovator characteristics as at the time of innovation. According to the applications for funding made to Tekes[5] , 1 Jan 2000 − 30 Jun 2002, the average length of R&D projects was 1.5 years.[6] Second, I want to (at least to some extent) account for endogeneity of financial characteristics of the innovator. If the patent itself is not a means to protect the innovation but rather a signalling device, contemporaneous characteristics such as profitability or size may be endogenous. Thus, patents applied for in 1986 were excluded because there is no information on financial statements for patents before 1986 (1935 patents matched).

Unfortunately the estimates could not be done using 1935 patents. There are missing observations for turnover (1314 patents are matched), wage per employer (746 patents matched), EBITDA (740 patents matched), and leverage costs (743 patents matched). In the final

[5]Tekes is the Finnish funding agency for technology and innovation. In 2006, 28% of the total 17000 million of government input in R&D was allocated by Tekes. http://www.tekes.fi/eng/publications/A_technopol/RD-Finland.PPT#4

[6]Based on discussion with Tanja Tanayama and Tanayama (2007).

regression there are 737 patents and these patents are from cohorts 1988 and 1989.

Hence, the final data set is marred by gaps, which have to be accounted for when interpreting the results. The patents analysed are patents owned by large firms, and more importantly large firms for which there were financial data. Table A1 gives an example of what the data look like.

3.2 Descriptive statistics

Table 1 gives the descriptive statistics.

Table 1: Descriptive statistics

No. of patents	737
No. of firms	70
Application year (cohorts)	1988−1989
Granted	1989−1999
Estimated Kaplan-Meyer age	7.2 years
Percentage of censored patents	26

There are 70 firms owning the 737 patents. This means that a firm on average owns 10.4 patents. However, 40% of firms only have one patent and 50 % of patents have no more than two patents. Also, 75% of firms have less than 8 patents and 90% of all firms have less than 30 patents.

The patents were applied for in 1988 and 1989. The grant date is on average 2.75 years after application, but some patents are granted after one year whereas some patents have to wait 10 years for a decision.

The age of the patent is calculated to begin in the year of application. Thus a patent applied for in 1988 and granted in 1990 can be renewed until 2008. The Kaplan-Meyer estimate for mean survival length is 7.2 years. The Kaplan-Mayer estimate takes into account that we do not observe the whole life span for each patent and therefore in this measure censored patents are also taken into account.[7] On all patents in the data 26% are censored, which means

[7] The Kaplan-Meier estimator, $\hat{K}(T)$ is a non-parametric maximum likelihood estimate of the probability that a patent is renewed until year T. It is defined as $\hat{K}(T) = \prod_{t \leq T} \frac{n_t - d_t}{n_t}$,where n_t is the

that these patents were still in force when the observation period ended (year 2003).

The initial distribution, R_{i0}, is a function of patent characteristics as well as patent-owner characteristics. There are four important patent owner characteristics. The size of a company is measured by turnover or by the number of employees. Second, the quality of the workforce, productivity, is measure by the average wage per employee. Third, I measure firm profitability by the ratio of earnings before interest, debt, taxes depreciation, and amortisation (EBITDA) to turnover. Finally, leverage is measured by the leverage costs divided by turnover. Thus, I take into account both the costs of leverage and profitability. This is important because firms with cash flow constraints are not necessarily financially constrained (Kaplan and Zingales 2000, 1997).

The summary statistics for these patent-owner characteristics are given in Table 2. All financial characteristics are measured one year before the patent application was made (in $t-1$).

Table 2: Patent owner characteristics, 737 patents

	mean	**5%**	**50%**	**95%**
turnover$_{t-1}$**(mil. EUR)**	85	3.2	55.2	538.9
employees$_{t-1}$	4 453	395	3 985	13 859
average wage$_{t-1}$	23.4	17.8	23.8	28.6
leverage costs$_{t-1}$	.05	.01	.04	.11
profitability$_{t-1}$	.13	.07	.13	.38

I also control for the industry in which the firm operates by measuring it to one digit level (version TOL88). The majority of firms are manufacturing firms (72.3%), but a large share are also technical and business services (18.7%). The third largest industry is wholesale and retail trade (6.8%). The distribution of firms by industry is depicted in Table 3.

number of survivors less the number of losses, ie the number of patents at risk at time t. d_t is the number of terminated patents at time t .

Table 3: Distribution of industry, 737 patents

	Percentage
1. mining and quarrying	.4
2. manufacturing	72.3
3. energy and water supply	1.4
4. construction	.27
5. wholesale and retail trade	6.8
6. transports	.1
7. technical and business service	18.7

The patent characteristics I control for are technology and breadth. I construct both technology and breadth from the international patent classification (IPC).[8] Specifically, I use the first IPC code given to the patent. A patent is often given many IPC classifications, but in Finland the first classification is the one that best describes the innovation (Patentti ja rekisterihallitus 2008, page C-9).

The six technologies are chemical and pharmaceutical (che), consumer goods and civil engineering (con), electrical engineering (ele), instrument (ins), mechanical engineering (mec), and process engineering (pro). The distribution of patents by technology is summarised in Table 4. Process engineering patents is the largest group (35%) and mechanical engineering patents is the second largest group (22%). Only 5 % of all patents belong to consumer goods and civil engineering patents.

Table 4: Distribution of patents by technology, 737 patents

	Percentage
chemical and pharmaceutical patents (che)	10
consumer goods and civil engineering (con)	5
electrical engineering (ele)	18
instruments (ins)	10
mechanical engineering (mec)	22
process engineering (pro)	35

[8] I use IPC version 7. I construct six technologies based on Nikulainen et al. (2005). Also Deng (2007b) constructs her own technology variable based on the IPC classification.

The breadth of the patent measures the degree of patent protection. I use the hierarchical structure of the IPC system to construct the variable breadth. There are nine hierarchies (breadths) in the IPC system and I call the highest hierarchy very broad. Few patents are very narrow and therefore I sum the six narrowest hierarchies to one breadth. Altogether there are four breadths (very broad, broad, narrow, very narrow). Breadth, as it is defined here, corresponds most closely to the definition of Klemperer (1990) and Waterson (1990), where breadth is defined as the space between the patented product and the nearest substitute.

The distribution of patents by breadth is depicted in Table 5. Of all patents 38% are broad. Every fourth patent is very broad or narrow (25% and 26%).

Table 5: Distribution of patents by breadth, 737 patents

	Percentage
very broad	25
broad	38
narrow	26
very narrow	11

In the estimations I also use the renewal costs. The renewal fees are equal for all patents from the same cohort, ie there is no difference between large and small firms. The renewal fee is increasing in age of patent. The lowest yearly renewal fee is 41.4 euros and the highest is 585.5 euros.

4 Results

This section first presents the results from the parameter estimations. The calculated distribution of the private value of patents based on the estimated parameters follows.

4.1 Estimated parameters of the initial distribution

Table 6 depicts the estimated parameters of the initial distribution, the decay rate, and the yearly shocks. The initial distribution is a function of firm characteristics as well as patent characteristics. The first column (1) shows the results when size is measured by turnover, and in the second column (2) size is measured by the number of employees.

I allow the financial variables to vary in size intervals. Winter (1984) predicted that different factors affect innovation in small and large firms and Acs and Audretsch (1988) found evidence for this. I therefore construct three different sizes and examine whether financial characteristics affect private value of patents differently by size. Small and medium sized firms (sme) are firms with less than 250 employees. Middle sized firms (mid) have less than 1000 employees but more than 249 employees, and large firms (max) have more than 999 employees.

As in Lerner (2006), I use the logarithms of all independent variables that are not ratios or dummies.

Table 6: Estimated parameter values

	1	**2**
μ	10.83(.045)***	10.66(1.137)***
σ_a	1.55(.044)***	1.45(.045)***
$1-\delta_{1-5}$	.58(.055)***	.62(.051)***
$1-\delta_{6-10}$	.62(.048)***	.66(.042)***
$1-\delta_{11-15}$	.66(.043)***	.70(.039)***
$1-\delta_{16-20}$	.66(.041)***	.70(.037)***
size	-.35(.065)***	-1.65(.174)***
size^2	-.023(.014)*	.39(.058)***
wage$_{t-1}$ **sme**	1.17(.572)**	4.40(.586)***
wage$_{t-1}$ **mid**	.17(.295)	1.05(.269)***
wage$_{t-1}$ **max**	1.42(.332)***	1.520(.256)**
leverage costs$_{t-1}$ **sme**	-17.12(10.818)	-53.88(7.678)***
leverage costs$_{t-1}$ **mid**	-3.17(3.871)	-13.96(3.916)***
leverage costs$_{t-1}$ **max**	1.36(.982)	3.95(1.023)***
profitability$_{t-1}$ **sme**	2.57(.845)***	-1.43(.854)*
profitability$_{t-1}$ **mid**	19.54(1.746)***	52.82(1.704)***
profitability$_{t-1}$ **max**	1.735(.488)***	5.13(.627)***
σ_ε	.39(.088)***	.37(.084)***
wald chi	326.5	312.11
prob>chi2	.00	.00
logL	-1818.2	-1838.6
# patents / # observ	737/8084	737/8084

Standard errors in parentheses. ***,**,* = significant at 1%, 5%, and 10%. The estimation also includes 5 patent technology dummies, 3 patent breadth dummies, 2 industry dummies, and a year dummy.

Size

Size has a negative impact on the private value of patents. The result is robust for measuring size by turnover (1) and number of employees (2). One explanation for the result is that larger firms may be more motivated to engage in portfolio strategies and hold on to patents that are not necessarily valuable in their own right, but together with other patents build up a patent thicket. However, whether this is the case cannot be investigated with this model, as it assumes that the renewal decision for every patent is independent of other patents in the portfolio.

Another explanation for the result may be that larger firms export more than small firms. Therefore the private value of patents in Finland may be smaller for larger firms than for firms that focus more on the domestic market. However, the identities of the firms are secret in the data and I cannot test this hypothesis.

But the result here that size has a negative impact on the private value of patents is counterintuitive because it is at odds with most of the previous research, most importantly with the results from essay 1 and essay 2. The possible reasons for this are twofold. First, there may be asymmetries in the ability to obtain external financing between firms of different sizes. In studies where financial characteristics are not controled for, size may be a proxy for the ability to obtain finance. Here I control for a set of financial characteristics and hence find that size is negatively correlated with the private value of patents.

Second, the sample used here is weigthed toward large firms.[9] Thus, factors driving differences between large and small firms in previous studies are not relevant here. These factors may for example be differences in the probability of commercializing the patent[10], or differences in the ability to enforce patents (Warshofsky 1994, Arundel 2001).

Leverage costs

Leverage costs have a negative impact on initial returns from patent protection for firms with less than 1000 employees. The effect of leverage costs is positive for large firms. This result suggests that the effect of leverage costs decreases the private value of patents among small and medium sized firms. Thus, under the assumption that firms need to raise capital to internalise patent revenues, it seems that smaller firms with much debt will have a disadvantage in doing so.

This result suggests that capital markets have not functioned perfectly for SME:s wanting to internalize revenues from patents. There is empirical evidence from Finland that capital market imperfections decrease investment in innovation (Hyytinen and Toivanen 2005). Thus, the conclusion is that not only investment in innovation, but also the internalization of patent protection suffers from imperfect financial markets in Finland.

[9] There are three firms with less than 100 employees in the data.

[10] Braunerhjelm and Svensson (2007) investigate commercialization of patents and find that commercialization is weak when an inventor commercializes his patents in his own firm.

The result here is not intuitive. It is easy to understand that it is hard to obtain financing for R&D projects because before a research project commences there is uncertainty about both the technology and the commercialization of the innovation. However, it should be easier to obtain external financing for extracting revenues from an already granted patent. Once a patent is applied for, there is less risk regarding the technology.[11] However, the results suggest that there also is substantial uncertainty related to commercialization and that this restricts the internalization of patents. Therefore, not only should R&D investment be subsidised, but also commercialisation of innovation, at least for SMEs.

The above interpretation assumes that patents are a means to protect innovation, but patents are often themselves the goal, not the means (Macdonald 2004). Another explanation for a negative correlation between leverage costs and private patent value is that firms apply for patents and renew them because they are financially constrained, and want to signal their good quality to financiers. There is evidence that patents are used as quality signals (Long 2002, Mann 2005, Heeley et al. 2007), that patents make it easier for start up companies to obtain external financing (Hsu and Ziedonis 2007, Baum and Silverman 2004, Mann and Sager 2007), and that patents also facilitate commercialization Gans et al. (2002). Also, Hyytinen and Väänänen (2006) find that among small and medium sized Finnish firms, ex-ante informational asymmetries cause financial constraints more often than ex-post informational asymmetries.[12] Still, most previous evidence on firms using patents as signals is based on small and new firms and firms in the software or biotechnology industry whereas the sample here consists of firms from all industries.

To properly distinguish whether patents are a means to protect innovation or a signaling device, one would (again) need a model that allows for interactions between firms' patents and a longer panel that includes observations on financial characteristics for a longer period.

Profitability

The effect of profitability (EBITDA/turnover) is positive for the majority of the firms (exception: small firms in regression 2). Assuming that profitable firms have more internal means for exploiting

[11] After application, the scope of the granted patent is still uncertain.

[12] Their data consists of SME:s and come from a set of surveys conducted between December 2001 and August 2003.

patents, this result too suggests that imperfect financial markets may hinder the internalization of patented innovations.

But we do not know whether more profitable firms have more valuable patents or whether having valuable patents makes the firms more profitable. For example, Lerner (2006) finds that less profitable firms innovate more. Hoping to correct for reverse causality, I use lagged values of profitability in the estimation. Thus, we should be able to conclude that more profitable firms have more valuable patents.

Average wage

The average wage per employee has a positive effect on initial returns. The result that the average wage is positively correlated with returns from the patent is intuitive if we believe that higher wage costs means a more productive workforce. Thus the result suggests that more productive firms have more valuable patents.

As with profitability, we do not know if more productive firms have more valuable patents or if a firm with more valuable patents can afford to pay higher wages. Again the lagged values of average wages are used in order to correct for reversed causality.

Decay rate

This model allows one to investigate if and how the decay rate changes over the patent life. This is important because there is no reason to believe that the decay rate is constant over 20 years of patent life, as in the previous literature (Schankerman and Pakes 1986, Schankerman 1998).

Here I allow the decay rate to vary over time. The test results depicted in the appendix (A3) indicate that the decay rate is not constant over the entire patent life, and so I allow the decay rate to change every 5th year.[13]

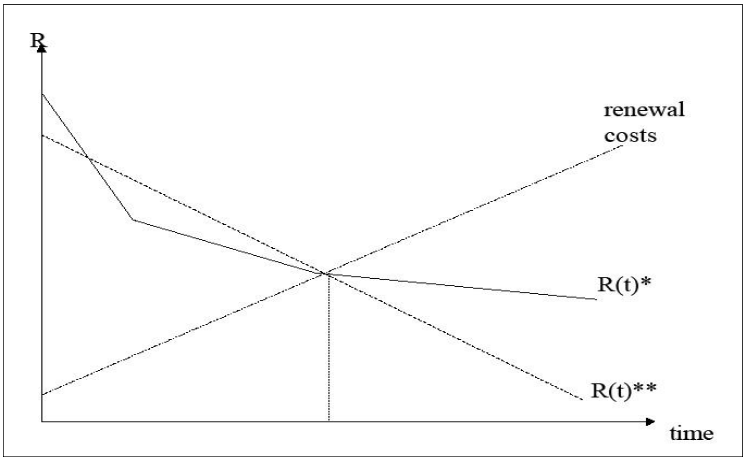
Results in Table 6 show that the decay rate is faster in the beginning of the patent life (δ_{1-5}=38%, 42%) and slows down toward the end (δ_{16-20}=30%, 34%). However, the decay rate is rapid over the whole patent life, and this points to fast technical turnover. For comparison one may note that for accounting purposes, the maximum decay rate for tangible assets is 25%. Hence, the estimates

[13]The assumption of a change in decay rate every fifth year is ad hoc. I have tried different specifications and found that the decay rates does not seem to change more often.

here imply that intangible assets decay faster than tangible assets. Previous findings suggest that the decay rate is lower than that found here: Bessen (2008) finds that the decay rate is at most 27% and Koléda's (2005) maximum estimate is 25%. Schankerman (1998) finds that electronic patents depreciate at the fastest rate, 19.2%, and Schankerman and Pakes (1986) find that the maximum decay rate is 26%. Furthermore, in essay 1, I find a maximum decay rate of 24%.

Figure 1 shows how revenues evolve when the decay rate can vary over the patent life, R(t)*, and when the decay rate is constant, R(t)**. I find that the decay rate is highest in the early part of the patent life and then decreases. This means that when observing the patent life and estimating the decay rate and the distribution of initial returns, the assumption of a constant decay rate may lead to under-estimated revenues in the early part of the patent life. Consequently, if the discount factor is large, the estimated private value of patents is too low when a constant decay rate is assumed.

Figure 1: Evolution of revenues when decay rate varies over patent life (R(t)*) and when assumed constant (R(t)**)



4.2 Distribution of private patent value

Having obtained the parameters, I use them to simulate the private value of patents. To do this I generate the initial distribution of random shocks, R_{i0}, and the yearly shocks, ε_{it}, by taking 50 000 pseudo draws for each shock (each draw for the initial return can be interpreted as a patent, ie I calculate the distribution of the private value of patents based on 50000 simulated patents). Then I calculate the revenue, R_{it}, for each age using the parameters estimated and the randomly drawn shocks (equation 2). The next step is to calculate the optimal life for each pseudo draw. If estimated revenues are higher than renewal costs, the patent is renewed (equation 3). Having calculated the optimal life of each pseudo draw, I then estimate the private present value of Finnish patents, using equation 1.

Table 7 shows the distribution of an ’average’ patent owned by an ’average’ firm. Column 1 uses the parameter estimates from regression 1 and column 2 uses the parameter estimates from regression 2. An average patent is a patent from cohort 1988. It protects a process engineering innovation and belongs to the breadth ’broad’. The average firm operates in the manufacturing sector and has 4 453 employees or a 85 million euro turnover, and the average annual wage for its employees is 23 400 euros. The leverage costs amounts to 5% of the turnover, and the EBITDA-to-turnover ratio is 0.13. (Table 2)

Table 7: Simulated value distribution for an average firm owning an average patent (values in year 2000 euros). The discount rate is set at 10%.

	1	**2**
quantile		
0.25	3 352	3 032
0.50	10 584	9 177
0.75	31 442	25 997
0.90	83 922	66 469
0.95	158 890	115 680
0.99	455 243	311 213
mean	38 008.8	29 189.1

The average value of about 38 000 and 29 000 euros is smaller than the estimates for Norway, US, and EPO patents. But the estimates are higher than the previous estimates using Finnish data.[14]

To find whether the difference between the results here and in essay 1 derive from differences in the data or from different assumptions in the models I estimate the Schankerman and Pakes (1986) model used in essay 1 on all firm patents from 1988 and 1989 (Table A4). I also estimate the model for the patents used in this paper

[14] Table A2 depicts previous estimates of the private value of patents using the Schankerman and Pakes (1986) model.

(Table A5). In essay 1, I find that the mean value of firm patents from cohorts 1971 to 1989 is 6 606 euros. I find that the mean value of firm patents from cohorts 1988 and 1989 is 5 971 euros (Table A4). But when I use the data from this paper and estimate the same model, I find that the average value is about 25 000 euros (Table A5). Thus, a large part of the difference between this study and the average value found in essay 1 is due to differences in the data.

The average value of 38 000 and 29 000 euros is, however, higher than the estimate I get using the model of Schankerman and Pakes (1986). One probable reason is allowing the decay rate to vary over the patent life. As figure 1 shows, the assumption of a constant decay rate may underestimate the private value of the patent. Another reason is that the mean value is calculated here for a specific type of patent. As essay 1 showed, there are large differences among patents that protect innovations from different technologies.

The estimated value, for several reasons, is the lower bound of the value of a granted patent. First, the estimates are based on renewal rates. Hence, the estimated private value is the minimum private value needed for the patent to be renewed. Second, I only use Finnish patents in Finland. Pakes and Simpson (1989) show that the renewal curves of domestic patent owners are significantly lower than renewal curves of other patentees. Third, the patent has a strategic value that may be correlated with other patents in the patent portfolio of the patentee. Here I assume that the decision to renew a patent is independent, and hence the strategic value of a patent portfolio is neglected.

Comparative statistics

Table 8 depicts the percentage changes in the mean value when firm characteristics are changed. Column 1 gives the differences for the parameter values from column 1, Table 6, and column 2 gives the differences for parameter values from column 2. It is important to notice that the comparative analysis in 8 only changes the mean of the initial distribution. The standard deviation and the decay rate remain constant.

The reference case is the ’average patent’ owned by ’an average firm’. An average patent is a patent from cohort 1988. It protects a process engineering innovation and belongs to the breadth ’broad’. The average firm operates in the manufacturing sector and has 4453 employees or a 85 million euro turnover, and the average annual wage for its employees is 23 400 euros. The leverage costs amount to 5% of the turnover, and the EBITDA-to-turnover ratio is 0.13. (Table 2)

Case a) depicts the change in the mean value when the average wage per employer increases by 10%. I find that the mean private value of patents increases 17% and 7% when the size increases by 10%. Thus, the productivity of the work force has an non-negligible impact on the private value of patents. Moreover, the size of the firm has an effect on the private value of patents (case b). A 10% increase in size decreases the private value of patents by 5% and 10.8%. However, the effect of changes in leverage costs (c) and profitability (d) are smaller. Finally, it appears that, even though the patent owner's financial characteristics affect the private value of patents, the industry in which the firm operates is much more important. Firms that operate in the technical and business survey industry have much more valuable patents than the reference case.

Table 8: Comparative statistics, percentage change in mean private value of patents

	1	**2**
a	17.2	7.1
b	-5.1	-10.8
c	3.8	3.3
d	1.4	6.8
e	146.2	44.7

The reference case: Large manufacturing firm. Size: turnover 85 (equation 1), employees 4 453 (equation 2). Leverage costs/turnover: 5%. EBITDA/turnover: 13%. Average wage: 23400. Breadth: broad. Technology: process and engineering patent. Cohort: 1988.

a. Percentage change in value distribution for firms with 10% higher wage costs

b. Percentage change in value distribution for firms with 10% larger size

c. Percentage change in value distribution for firms with 10% higher leverage costs.

d. Percentage change in value distribution for firms with 10% higher profitability.

e. Percentage change in value distribution where firm is from industry 'technical and business service'.

5 Conclusion

I estimate how the characteristics of the patent owner affect the private value of patents. I contribute to the line of research that estimates the private value of patents in two ways. First, I combine patent data with financial data. Second, I extend the model of Schankerman and Pakes (1986).

I find that the value of the patent is affected not only by patent characteristics but also by characteristics of the patent owner. The size of the firm has a negative impact on the private value of patents. I also find that firms with higher average wage costs have more valuable patents. I find that smaller firms with high leverage costs have patents of lower value. Together with the finding that more profitable firms have more valuable patents, this finding suggests that firms have to use internal funds to appropriate revenues from patents. This suggests that there are financial imperfections and that not only innovation but also commercialization of innovations should be subsidized.

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A Appendix

Table A1: An example of what the panel data looks like

patent	**owner**	**applied**	**renewed until**	**year**	**renewed**	**age**	**technology**	**turnover**$_{t-1}$	**cost**
1	1	1988	1992	1988	1	1	con	turnover_{1987}	41.4
1	1	1988	1992	1989	1	2	con	turnover_{1987}	44.1
1	1	1988	1992	1990	1	3	con	turnover_{1987}	48.8
1	1	1988	1992	1991	1	4	con	turnover_{1987}	95
1	1	1988	1992	1992	1	5	con	turnover_{1987}	115.4
1	1	1988	1992	1993	0	6	con	turnover_{1987}	140.1
2	1	1988	still in force	1987	1	1	ele	turnover_{1987}	41.4
2	1	1988	still in force	1988	1	2	ele	turnover_{1987}	44.1
…	…	…	…	…	…	…	…	…	…
2	1	1988	still in force	2003	1	16	ele	turnover_{1987}	585.5
3	2	1988	1996	1988	1	1	mec	turnover_{1987}	41.4
…	…	…	…	…	…	…	…	…	…

Table A2: Previous estimations of private value of patents using deterministic model of Schankerman and Pakes (1986) (values in year 2000 euros). Discount rate is 10% and initial returns follow a log normal distribution.

	mean		**mean**
UK 1970[1]	9 400	pharmaceut. 1970[2]	5 823
France 1970 [1]	8 986	chemicals 1970[2]	6 708
Germany 1970 [1]	25 818	mechanical 1970[2]	20 412
EPAT 1985 [3]	92 478	electronics 1970 [2]	92 478
Norway 1980−94 [4]	119 842	US in JP 1974[5]	131 037
UK 1974[5]	152 286	US in DE 1974 [5]	211 607
France 1974 [5]	177 962	JP in US 1974 [5]	287 749
Germany 1974 [5]	245 251	JP in DE 1974[5]	177 962
Japan 1974[5]	145 203	DE in US 1974 [5]	563 989
US 1974 [5]	397 537	DE in JP 1974[5]	145 203
UK & Ireland 1870−72 [6]	11 059	US 1991[9]	66 030
France 1980 [7]	10 845	EPO in DE 1978−1996[10]	768 906
India 1962−71[8]	1 484	Finland 1971−1989[11]	7 551
India 1972−85 [8]	2 310	This study	38 009 / 29 189

[1]Schankerman and Pakes (1986), value from age five until the patent lapses.
[2]Schankerman (1998), patents from DE, FR, UK, JP, and US applied for in France.
[3]Duguet and Iung (1997), EPAT= European patent.
[4]Maurseth (2005) , yearly return at age 0.
[5]Putnam (1996), application costs included, US in JP = Patents from US applied for in Japan.
[6]Sullivan (1994), values at age 3 (max length of patents 14 years).
[7]Koléda (2005), discount rate 5%.
[8]Fikkert and Luthria (2000), initial distribution: exponential, only electricity patents.
[9]Bessen (2008), all US patents from cohort 1991, patent level data.
[10]Deng (2007b), EPO-German patents.
[11]Essay 1, cohort level data.

Exchange rates: www.federalreserve.gov/releases/H10/hist/default1989.htm and Duguet and Iung (1997).

Table A3: Test of equality in decay rates. Tables depicts χ^2 value for a test of equal decay rates from Table 6. Parts 1 and 2 give the results of test of whether decay rate in columns 1 and 2 (table 6) respectively change during the patent life. ***,**,* = significant at 1%, 5%, and 10%.

1.

	$1-\delta_{6-10}$	$1-\delta_{11-15}$	$1-\delta_{16-20}$
$1-\delta_{2-5}$	11.89***	27.06***	24.50***
$1-\delta_{6-10}$		36.68***	23.92***
$1-\delta_{11-15}$			.15

2.

	$1-\delta_{6-10}$	$1-\delta_{11-15}$	$1-\delta_{16-20}$
$1-\delta_{2-5}$	6.54*	18.83***	16.51***
$1-\delta_{6-10}$		41.78***	24.14***
$1-\delta_{11-15}$			.02

Table A4: Distribution of private value of patents using Schankerman and Pakes (1986) model, estimated over all firm patents from cohorts 1988 and 1989

	value distribution
quantile	
0.25	274
0.50	1 245
0.75	4 737
0.90	13 419
0.95	24 406
0.99	68 392
mean	5 791.4

Table A5: Distribution of private value of patents using Schankerman and Pakes (1986) model; data are those used in this paper

	value distribution
quantile	
0.25	507
0.50	2 664
0.75	12 998
0.90	45 862
0.95	98 155
0.99	355 538
mean	25 293.6

Essay 4: The optimal patent length is shorter than 18 years

Contents

Abstract

The statutory limit of patents was extended from 17 to 20 years in Finland in 1980. I find, using non-parametric testing, that this change did not change the renewal rates of patents. This means that the private value of the patent was not affected by the longer statutory length. Based on Nordhaus (1967), I conclude that the optimal patent length is shorter than 18 years.

1 Introduction

The question whether we should have a patent system and how it should be designed is not new, but it still is very relevant (see Machlup 1958 and Machlup and Penrose 1950 for a review of the debate of the nineteenth century). Machlup (1958) and Arrow (1962) initiated the discussion on the optimal patent length and it was later formalised by Nordhaus (1967, 1969). Since then, many papers have discussed and modeled the optimal patent length.

However, empirical evidence on optimal patent length is almost non-existent. Therefore, I contribute empirically to the discussion of the optimal patent length. I test non-parametrically whether the law reform that extended the statutory life of patents from 17 to 20 years in Finland in 1980 changed the renewal rates of patents.[1] I use the change in the patent legislation as a natural experiment to draw conclusions on the optimal patent length and contribute empirically to the literature on optimal patent design.

The aim in changing the statutory limit is naturally not to change renewal behavior but to design an optimal patent policy that balances the tradeoff between incentives to the innovator and the welfare loss from patents. Renewal rates together with non-parametric tests can, however, be used to draw conclusions about the optimal patent length. Assume that the private value of the patent in age t, V_t, is $V_t = r_t - c_t + \beta E_t(V_{t+1})$(Pakes 1986). The private value of patents is composed of two parts; net revenues at age t, $r_t - c_t$, and the expected value for future periods, $\beta E_t(V_{t+1})$. r_t are the patent revenues that may decline or become obsolete. c_t denotes the yearly renewal fees at age t, and β is the discount rate. Presumably the patent is not renewed if its revenues, $r_t + \beta E_t(V_{t+1})$, are less than renewal costs, c_t. A change in patent legislation that lengthens the statutory limit should increase the expected value for future periods, $E_t(V_{t+1})$, because the time during which one can use the patent is longer. Consequently the yearly renewal decision should change if the private value of patents increases when the legal rights of patents are prolonged.[2]

If we observe significantly higher renewal rates after the statutory

[1] Finland makes a good case for inferring results on optimal patent length because when this law was changed, other things were kept constant. In Germany, for example, the renewal fees and the statutory length were simultaneously changed in 1977 and therefore it is hard to know the specific effect of each change (Lanjouw 1998).

[2] Duffy (2005) discusses the dynamic aspects of a longer statutory limit and the effects on the timing of investment in research and patenting. However, here I focus on the immediate effect of the change in the law on already-granted patents.

length is increased from 17 to 20 years, this means that the private value of patents has increased as a result.[3] On the other hand, if there is no change in renewal rates after an increase in the statutory length, this implies that the private value of the patent did not increase despite the extention. This may be the case if the change in expected value of having a patent for three more years is so small that the prolonged patent length does not change the renewal behavior significantly. If this is the case, ie if for example technological progress renders patents obsolete before the legal deadline, the optimal patent length is less than the economic life of the patent (Nordhaus 1967 page 22). Thus, if there is no change in renewal behavior due to the change in statutory limit, one can infer that the economic life of patents is no longer than 17 years and so the change in patent law was not optimal.

Since much discussion on optimal patent design focuses on patent length and breadth[4], I construct my own variable for patent breadth and test whether the change in patent length affected patents of different breadth differently. I also test whether the change in statutory limit changed the renewal behavior differently for patents of certain technologies or certain types of applicants.

This paper relates most closely to Lanjouw (1993). The statutory life of patents was extended in Germany in 1977, and Lanjouw investigates how this changes affected renewal rates using the log-rank test. Unfortunately, the renewal fees were changed in the same year, which makes it difficult to draw conclusions.

This paper also relates to Deng (2007a), which compares the private value of European patents using the model of Pakes (1986) as the theoretical framework. Many countries changed statutory limits of patents and renewal fees when they joined the European Patent Convention. Deng (2007a) finds that both changes in statutory limit and renewal fees had only a modest impact on the mean private value of patents.

There are two other empirical papers that touch on optimal patent policy. Both of these papers use historical data. Lerner

[3]The assumption needed for this to be true is that r_t and c_t do not change as a result of a longer statutory life.

[4]The optimal patent system has been modeled based on optimal patent breadth or on the tradeoff between breadth and length. Various assumptions regarding competition, imitation, endogenous entry, and patent races have been considered (Klemperer 1990, Gilbert and Shapiro 1990, Gallini 1992, Dijk 1996, Wright 1999, Denicolò 1996, Kanniainen and Stenbacka 2000, Takalo 2001). The models on one innovation have been followed by a myriad of models on optimal patent systems where innovation is multistage or cumulative or sequential (Scotchmer and Green 1990, Scotchmer 1991, Green and Scotchmer 1995, Chang 1995, Scotchmer 1996, Matutes et al. 1996, VanDijk 1996 O'Donoghue et al. 1998, O'Donoghue 1998).

(2002) investigates whether differences in strength of national patent laws correspond to the theory of Nordhaus (1969). According to Nordhaus (1969), a country that is a technological leader (ie has relative economic strength) should have stronger patent protection than a follower. Lerner (2002) uses historical patent data from sixty countries to determine whether this is true. Moser (2005), on the other hand, empirically investigates how different patent laws influence innovation using data from 19th century world fairs. She finds that patent laws do not affect the amount of innovation as much as the areas in which innovations are made.

In addition to the above empirical treatments, we have some information on optimal patent length based on theoretical models of optimal patent policy. Nordhaus (1967) calculates the optimal life of patents by assigning reasonable values to parameters in his theoretical model. He finds that the optimal patent life for an average, non-drastic innovation is 9 years. Denicolò (2007) proceeds in a similar manner. He calculates whether innovators receive excessive returns from patents by assigning reasonable values to parameters in his model. His conclusion is that patents do not generate excessive rewards to assignees.

The idea of using non-parametric tests together with patent renewal rates is not new. Pakes and Simpson (1989) show that renewal rates can be used to non-parametrically order patents by value, and non-parametric techniques have been used by eg Schankerman (1998) and Deng (2007b) to test for differences in renewal rates between patents with different characteristics.

I find that the change in patent law did not change the renewal behavior. This result means that the optimal patent length is less than 18 years in Finland and hence that the change in patent law was not optimal.

The next section outlines the details behind the change in the law. This is followed by a description of the non-parametric tests and the data. Section 5 discusses the results and the last section summarizes.

2 Details of the new law

In 1968 the Patent Cooperation Treaty (PCT) and European Patent Cooperation (EPC) were planned and Finland's Ministry of Trade and Industry assigned a committee to investigate how the patent law in Finland should be changed in light of international cooperation in patent law.

Almost ten years later, in 1977, the committee published a report suggesting that the statutory length should be extended from 17 to 20, years to match the statutory length of European patents and the legislation in most important West-European countries.[5] This report was drafted in collaboration with similar committees from other Nordic countries.[6]

Three years after the report, in June 1980, the parliament decided that the statutory length is 20 years in Finland.[7] Also patents already granted could be extended for 20 years. This law was put into practice 1.10.1980 when the Finnish patent office started to charge renewal fees until the 20th year.

[5]Komiteamietintö 1977:38: Mietintö kansainvälisestä patenttiyhteistyöstä II, Euroopan patenttisopimuksen johdosta patenttilakiin tehtävät tarkistukset ISBN 951-46-2860-8.

[6]In 1976 the committee released its first publication, Komiteanmietintö 1976:9: Mietintö kansanivälisestä patenttiyhteyistyöstä, ISBN: 951-46-1284-, with suggestions for changes in the law in order to harmonize Finnish patent law with other countries' laws. Extending the patent length was not discussed in this report .

[7]Patent law 1980/409.

3 Method

I want to test whether the new law allowing assignees to renew their patents for 20 years instead of 17 years changed the renewal behavior. I compare the renewal rates for patents in 1981 to those in 1979, to clarify the difference between renewal rates before and after the legislative change. I use two different approaches to compare the renewal rates.

The first approach is to compare, at a specific age, the renewal rates before and after the change. In 1979 the patents from cohort 1970 were 10 years old and had the option to be renewed for 7 more years, whereas in 1981 patents from cohort 1972 (also 10 years old) had the option to be renewed for 10 more years. When comparing with renewal rates of 10 year old patents from cohort 1970 we should find a difference in the renewal rates of 10 year old patents from cohort 1972 if the prolonged patent life increased the private value of patents.

The second approach is to compare the whole survival function of patents before and after the change. The reason for doing this is that samples sometimes become small when testing only one point in time against another point in time.

3.1 Comparing survival curves at a single point in time

The first approach is to compare two survival curves at a single point in time. A naive test for comparing the equality of two survival rates is

$$\chi_1^2 = \frac{(S_1(t) - S_2(t))^2}{S_1(t)^2\sigma(t)_1^2 + S_2(t)^2\sigma(t)_2^2},$$

where $\sigma(t)_i^2$ is

$$\sigma(t)_i^2 = \frac{d_i}{n_i(n_i - d_i)}.$$

n_i is the total number of patents at risk of not to being renewed, d_i denotes patents that were not renewed, and $S(t)_i$ is the Kaplan-Meier survival rate at the specific point in time $(t).i = 1,2$.

Klein et al. (2007) study the properties of different estimators and find that a test based on a logarithmic and a log(-log(.)) transformation of the naive test perform the best. The type 1 error properties and the power of the tests both depend on sample size and censoring. When there is no censoring (as here) they perform well. When samples are larger than 90, the log(-log(.)) transformation performs very well regarding the type 1 error. Also the power is slightly better for the cloglog transformation than for the naive test or logaritmic transformation.

The logaritmic transformation is

$$\chi_2^2 = \frac{(log(S_1(t)) - log(S_2(t)))^2}{\sigma(t)_1^2 + \sigma(t)_2^2},$$

and the log(-log(.)) transformation is

$$\chi_3^2 = \frac{(log(-log(S_1(t))) - log(-log(S_2(t))))^2}{\sigma(t)_1^2/(log(S_1(t)) + \sigma(t)_2^2/(log(S_2(t)))}.$$

3.2 Comparing survival functions − Log-rank tests and Kolmogorov-Smirnov test

This section describes the tests that compare whole survival curves.

There is no point in testing whether the survival curves of two cohorts are similar because all cohorts were at some point affected by the law change. I therefore create two hypothetical survival curves. The first hypothetical survival curve is for the renewal rates of 10 year old patents from cohort 1970, the survival rates of 9 year old patents from cohort 1971 etc. Thus, the first survival rate consists of patents that had the option to be renewed for 17 years. The second hypothetical survival rate is for renewal rates of 10 year old patents from cohort 1972, the survival rates of 9 year old patents from cohort 1973 and so on. These are patents that had the option to be renewed for 20 year. The testing here can be thought of a summation of the tests in section 3.1.

One group of non-parametric tests suitable for comparing two or more samples comprimises weighted log-rank tests (eg the log-rank test, Peto and Peto's log-rank test, the Cox Mantel test, the Mantel-Haenszel test, Gehan-Wilcoxon test, and Peto and Peto's generalised Wilcoxon test) (Pyke and Thomson 1986).

The asymptotic properties of the log-rank test (and other rank tests) have been extensively studied. The log-rank test statistic is consistent under the assumption that the failure of one of the groups tested is a constant multiple, e^x, of the other group. It converges to the standard normal distribution. The log-rank test has optimal power among rank-invariant tests for detecting differences between survival functions. However, it is not clear how the log-rank test behaves in small samples. Specifically, when the hazard rates of the two tested distributions are not proportional (eg due to different depreciation rates), the Wilcoxon test has more power than the log-rank test. The greatest disadvantage of the log-rank type of tests is that they can fail if two hazard rates cross.

Another group of non-parametric tests suitable for comparing the equality of two survival distributions are generalizations of Kolmogorov-Smirnov statistics. The advantage of this test is that is performs better when hazard rates cross.

Another advantage of the generalized Kolmogorov-Smirnov statistic is that it can be used not only to compare survival distributions but also to infer stochastic dominance. First-order stochastic dominance means that the renewal rates are higher for one group of patents than for another from the first until the 20th year, ie each year there is a larger proportion of patents with revenues exceeding renewal fees in the first group than in the second group. Stochastic dominance testing facilitates the ranking of patents based on their private values.

McFadden (1989) introduced a generalization of the Kolmogorov-Smirnov test to test first and second order dominance between independent distributions. I use the test for first order stochastic dominance also here, but with samples of possibly different sizes as in Barrett and Donald (2003). The test by McFadden (1989) relies on testing the supremum statistic of the difference between empirical distribution functions. This test has been used in many application, eg Scaillet and Topaloglou (2005), Maasoumi and Hesmati (2000), Linton et al. (2005), and Maasoumi and Heshmati (2005).[8]

The empirical cumulative distribution functions used to test stochastic dominance are F_i and F_j, where F_i is the cumulative failure function of patents from group i. To infer first-order stochastic

[8]The Kolmogorov-Smirnov test is not the only test for stochastic dominance. Instead of using the supremum statistic to infer stochastic dominance an area statistic could be used (Schmid and Trede 1996) or, instead of distribution-functions, quantiles can be employed (Xu et al. 1995).

Another approach to infer stochastic dominance is to compare distributions at a finite number of grid points. Anderson (1996) tests stochastic dominance using t-statistics of two independent samples and Davidson and Duclos (2000) use an inequality constraint to estimate stochastic dominance. In this line of research the null hypothesis is equality of both functions. One problem with this testing is that the alternative is not the complement of the null hypothesis and therefore a rejection of the null hypothesis does not necessarily mean dominance.

dominance, I test the null hypothesis

$$H_o : F_i \leq F_j. \quad (1)$$

The null hypothesis in this test is stochastic dominance. Thus, a rejection of the null hypothesis tells us that i does not stochastically dominate j, but further conclusions cannot be drawn. The reason for designing the test in this direction is that the set of non-dominance is complex.

The test statistic is $\hat{T}_j = (\frac{NM}{N+M})^{\frac{1}{2}} sup(F_i - F_j)$, where M and N are the sizes of the two samples and F_i is the empirical cumulative distribution of i. The decision rule is reject H_0 if $\hat{T}_j > c$, where c is a critical value. Interesting critical values are eg 1.073, 1.2239 and 1.5174 which are the limits for the 10%, 5%, and 1% significance levels. For first order stochastic dominance, the p-values can be calculated directly because $P(\hat{T}_j > c) = exp(-2c^2)$. Thus the p-value can be computed via $exp(-2\hat{T}_j^{\,2})$.

4 Data

I obtained the data from the National Board of Patents and Registration of Finland. The data set includes all Finnish patents granted after 1 Jan 1971. The data include the age of the patent (number of years renewed), type of assignee (firm or private person), and the international patent classification.

In the testing I use patents that were applied for before 1982. There is no censoring in the data, ie I observe the whole lifespan for all patents. The mean patent length for these patents was 9 years.[9] Almost 6% of these patents were renewed until the 20th year. The mean patent length in Finland corresponds to those reported in Schankerman and Pakes (1986) and Lanjouw (1998); they find that 50% of German patents reached an age of 10 years. Deng (2007b), on the other hand, finds that 70 % of European patents in Germany are kept alive until the tenth year.

Individual assignees applied on average for 40% of the patents. In Bessen's (2008) data set on US patents from 1991, 19% of patents were given to individuals (or unassigned).

Table 1: Descriptive statistics

No. of patents	4 688
application year (cohort)	1959−1981
grant year	1971−1993
% of firm patents	60

Each patent is assigned at least one international patent classification (IPC). Often a patent gets many classifications and in that case I use the first, which is the major one in Finland (Patenttikäsikirja 2008). I use the hierarchical structure of the IPC system to construct the variable breadth.[10] There are nine hierarchies in the IPC system. Almost 24% of Finnish patents belong the highest hierarchy, ie they are very broad, and 42% of the patents are assigned to the second broadest group of patents. I combine the six narrowest categories into one group (very narrow). These patents amount to less than 11% of all patents (Table 2).

[9]Kaplan-Meier estimate.

[10]I use version IPC 7.

Table 2: Distribution of breadths

	% of patents
very broad patents	23.5
broad patents	41.6
narrow patents	24.3
very narrow patents	10.6

The measure of breadth used here corresponds fairly well to the definition of Klemperer (1990) and Waterson (1990), ie patent breadth is the space between patented product and nearest substitute. For example, if a patent is for ’Traveling or camp articles: water bottles’, the difference versus the nearest substitute is greater than if the patent is for ’Traveling or camp articles: water bottles made of rigid material’. Water bottles in general are ’broad patents’ and water bottles made of rigid material are ’narrow patents’. The main problem with measuring breadth in this way is that the IPC classification is created by humans and evolves over time. Also, the difference between two products of the same breadth is not the same across technologies.

Different definitions of breadth have been used in theoretical literature on optimal patent design[11], but breadth has not gained much attention in the empirical work. Lerner (1994) measures the impact of patent scope on firm value also by developing a proxy for patent scope from the international patent classification. He counts the number of IPC classifications to which a patent is assigned.[12] Deng (2007b) also controls for the number of different technologies to which the patent is assigned. Having constructed the breadth variable, I can investigate how differently the change in statutory patent length affected patents across different breadths differently.

From the raw IPC classification I also construct technologies.[13] Again I use only the first classification. There are six technologies; chemical & pharmaceutical (che), consumer goods & civil engineering (con), electrical engineering (ele), instruments (ins), mechanical engineering (mec), and process engineering (pro). Mechanical engi-

[11] On the optimal patent design see eg Takalo (2001).

[12] Unfortunately my data set does does not include all IPC classifications, but only the major one, and therefore I cannot check the correlation between Lerner’s (1994) and my way of measuring breadth.

[13] The technologies are constructed as in Nikulainen et al. (2005).

neering patents is the largest group (33.55%), and process patents is the second largest group (23.44%) (Table 3).

Table 3: Distribution of technologies

	% of all patents
chemical & pharmaceutical	6.8
consumer goods & civil engineering	17.5
electrical engineering	9.9
instruments	9.5
mechanical engineering	33.6
process engineering	23.4

To keep a patent, the patentee must pay a yearly renewal fee set by the Ministry of Trade and Industry. The fees are equal for all patents from the same cohort, ie all patents applied for in the same year pay the same renewal costs. The renewal fee is increasing in the age of the patent.[14] The lowest yearly renewal fee in the data is 17.10 euros and the highest is 871.80 euros.[15]

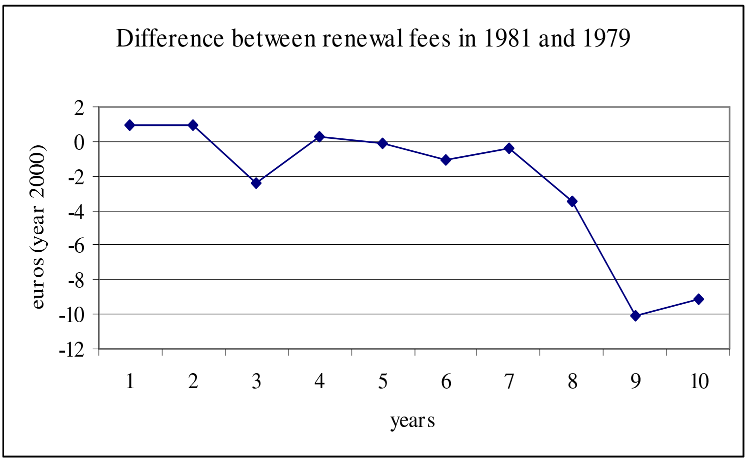
When testing for differences in renewal rates over time it is important that the renewal rates do not change. The Figure 1 below shows the difference in euros between the real renewal fees in 1979 and 1981. A positive value means that the renewal fees were larger in year 1981 than in 1979. On average the difference between the renewal rates are less than one percent of the total renewal fees during the first ten years.[16] Thus, one should be able to conclude that the renewal fees did not change much when the statutory length of patents was changed from 17 to 20 years. Consequently, differences in renewal rates between patents from 1979 and 1981 should be due to the difference in the option value.

[14]The renewal fee schedule changed in 1990 so that the renewal costs for the first three years are today paid together during the third year.Thus, the renewal fees paid are today not increasing in age because the fee charged in year 3 is larger than the fee charged in year 4.

[15]I convert annual fees to euros and, using an index for investments, I transform them to the price level of year 2000.

[16]The figure depicts only the first ten years because the renewal rates for these years are tested in section 5. The total average relative difference for the first through the 17th year is 0.1%.

Figure 1: Difference between renewal fees in 1981 and 1979



5 Results

5.1 Comparing renewal rates at a point in time

Table 4 depicts the results from tests that compare survival rates at a specific point in time. The first row includes all patents. I also report results by applicant (firm or individual), technology, and breadth. This allows me to examine whether an extension of the statutory limit affected different types of patents differently.

The columns give the different ages. The first column shows test results for whether 10 year old patents from cohort 1970 had different renewal rates than 10 year old patents from cohort 1972. 10 year old patents from cohort 1970 had the option to be renewed for 7 more years whereas 10 year old patents from cohort 1972 had the option to be renewed for 10 more years. Comparing the renewal rates of all 10 year old patents from cohort 1970, we should find a difference to renewal rates of 10 year old patents from cohort 1972, if the prolonged patent length increased the option value of patents. Table 4 shows that this is not the case. The test statistic for all three tests is .02, which is not significant.

I find almost no evidence that the change in statutory life would have changed the renewal rates of patents between between 1979 and 1981. There are no significant results for certain ages or certain types of patents.[17] There are several potential explanations for not finding changes in the renewal behavior. First, the patent owners may learn very fast[18] about the value of the patent. Moreover a small change in the statutory limit would not show up as a significant result. However, if this were true, we should see some significant results for the early years, which is not the case.

Second, patent owners learn very slowly about patent value. I cannot test the renewal rates at ages $11-17$ due to data limitations. If patent owners do not know whether a patents is valuable until it is more than 10 years old, I would not find any significant results here. But, the results in essay 2 show that learning how to use the patent is over by the 12th year for firms.

Third, patent owners are not forward looking. If patent owners care only about current returns, a change in statutory limit would not affect renewal rates. There are models that estimate the private value

[17] Many significant results are based on small samples and should therefore be interpreted with caution.

[18] Pakes (1986), Lanjouw (1998), Deng (2007a) find that learning is over fast.

of patents on the assumption that agents are myopic (Schankerman and Pakes 1986, Schankerman 1998, Deng 2007b, Bessen 2008). If one fails to get significant results is due to agents not taking forward patent returns into account, deterministic models could be used instead of time consuming stochastic models.

Fourth, patent owners knew already in 1977 that patent length would be extended and therefore I do not find any changes in renewal rates between 1979 and 1981. To check this possibility I compared survival rates between 1977 and 1976 but did not found any significant differences. The results are given in the Appendix.

Fifth, the private value of a patent implied by the renewal decision is a measure of how much the patent owner earns if he renews the patent versus not renewing it. This value is not the same as the patent premium (Arora et al. 2008) or the value of patent rights (Harhoff et al. 2003). The difference between the value of patent rights and the private value of patents is that the former takes into account that, if the assignee sells the patent, the assignee may be excluded from using the technology. If the patent lapses, the patent assignee is still allowed to use the technology. Even though the private value of a patent is not affected by the longer statutory limit, it does not rule out the possibility that the patent premium or value of patent rights is significantly higher when the statutory length is longer.

Sixth, the samples are small, especially for some technologies. Therefore it may be hard to find evidence of changes in renewal behavior and, if one did, the results would not be very reliable. I control for this in the subsection below by aggregating the survival curves.

Table 4: Test for differences in renewal rates in 1979 and 1981. *** ,**,*= significant at 1% , 5% , 10% level. Parentheses mean that there are significant differences in the renewal curves, but the difference is not according to theory, ie there are more failures in 1981 than in 1979, even though the sample is smaller in 1981.

		10	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
all	#obs	202	298	354	481	570	660	774	814	841	963
	failures	26	38	33	61	54	51	47	27	15	3
	naive	.02	6.27(**)	28.61(***)	.16	.57	.53	.62	**4.95****	.33	.19
	log	.02	6.25(**)	28.88(***)	.16	.57	.53	.62	4.89	.33	.19
	cloglog	.02	6.24	27.46(***)	.16	.57	.53	.62	4.80	.33	.17
firm	#obs	138	200	225	305	351	401	466	514	540	630
	#failures	13	32	16	27	30	26	25	13	6	1
	naive	.28	8.18(***)	**20.55*****	3.61(*)	5.75(**)	.00	1.22	1.15	.03	.00
	log	.28	8.05(**)	**20.67*****	3.61	5.81(*)	.00	1.21	1.14	.03	.00
	cloglog	.28	8.10(**)	**18.85*****	3.50	5.25	.00	1.20	1.15	.03	-
ind.	#obs	64	98	129	176	219	259	308	300	301	333
	#failures	13	6	17	34	24	25	22	14	9	2
	naive	.57	1.44	10.88(***)	**9.99*****	1.97	.54	.00	**4.00****	.59	.00
	log	.56	1.44	10.99(***)	**9.86*****	1.96	.54	.00	3.93	.59	.00
	cloglog	.56	1.44	10.73(**)	**9.84****	1.97	.53	.00	3.69	.54	.00
che	#obs	19	17	34	28	48	46	46	62	56	79
	#failures	1	0	0	3	3	4	2	1	1	0
	naive	.75			1.51	.19	.15	.13	.00	.00	
	log	.78			1.50	.19	.15	.13	.00	.00	
	cloglog	.71			1.39	.19	.14	.12	-	-	
con	#obs	20	52	40	84	91	113	135	133	151	170
	#failures	3	5	7	14	8	9	9	5	5	2
	naive	**8.58*****	.34	3.17(*)	1.73	**3.84***	**8.33*****	.53	.41	.13	.04
	log	**9.49*****	.34	3.17	1.76	3.71	**8.25****	.53	.40	.13	.04
	cloglog	**8.82****	.34	3.15	1.69	3.74	**6.55***	.51	.41	.13	.04
		cont.									

		10	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
ele	#obs	20	30	42	42	64	47	77	52	62	66
	#failures	3	5	1	4	4	4	5	2	1	0
	naive	**61.59*** **	**26.14*** **	3.21(*)	.05	4.16(**)	.01	**6.00** **	.00	.00	
	log	**138.65*** **	**35.00*** **	3.16	.05	4.26	.01	**5.81***	.00	.00	
	cloglog	**63.67*** **	**23.13*** **	2.85	.05	3.11	.01	3.85	-	-	
ins	#obs	22	25	32	38	43	59	82	87	92	97
	#failures	5	3	5	8	3	7	5	6	1	0
	naive	.55	**12.15*** **	2.56	.00	.25	.12	**9.34*** **	1.27	.00	
	log	.55	**15.06*** **	2.70	.00	.25	.12	**8.06** **	1.24	.00	
	cloglog	.55	**10.77** **	2.42	.00	.26	.11	**6.26***	1.23	-	
mec	#obs	69	104	125	161	184	211	227	277	248	322
	#failures	5	15	12	19	22	14	18	8	5	0
	naive	**6.24** **	.64	**17.68*** **	.33	.30	1.54	11.06(***)	1.71	.09	
	log	**6.73** **	.65	**18.60*** **	.33	.30	1.53	10.51(***)	1.69	.09	
	cloglog	6.25	.64	**16.73*** **	.33	.30	1.51	9.39(**)	1.72	.09	
pro	#obs	52	67	80	121	139	179	206	203	231	229
	#failures	9	10	8	13	14	13	8	5	2	1
	naive	.13	.41	.02	.01	1.19	4.62(**)	1.26	1.32	.40	.00
	log	.13	.41	.02	.01	1.20	4.55	1.26	1.30	.40	.00
	cloglog	.13	.40	.02	.01	1.13	3.94	1.19	1.17	.38	
very broad	#obs	45	58	78	116	115	166	176	190	201	235
	#failures	8	6	10	14	9	9	10	5	2	1
	naive	10.45(***)	1.31	.22	3.94(**)	.72	.01	1.47	.29	.00	.00
	log	10.72(***)	1.29	.22	3.84	.72	.01	1.45	.29	.00	.00
	cloglog	10.42(**)	1.30	.22	3.90	.70	.01	1.42	.29		
		cont.									

		10	9	8	7	6	5	4	3	2	1
broad	#obs	85	116	138	204	236	268	330	340	357	403
	#failures	11	10	8	27	28	18	17	13	7	0
	naive	2.53	5.69(**)	6.71(***)	1.93	.23	.50	.36	5.99(**)	1.42	
	log	2.62	5.64(*)	6.81(**)	1.94	.23	.50	.36	5.81(*)	1.41	
	cloglog	2.53	5.65	6.53(*)	1.90	.23	.50	.36	5.35	1.31	
narrow	#obs	53	90	97	123	151	155	192	186	195	209
	#failures	6	16	12	17	13	16	10	6	5	2
	naive	1.59	.00	**18.77*** **	.11	.50	.01	3.59(*)	.13	1.84	.00
	log	1.64	.00	**19.33*** **	.10	.50	.01	3.51	.13	1.81	.00
	cloglog	1.59	.00	**16.85*** **	.11	.50	.01	3.32	.13	1.46	.00
very narrow	#obs	19	34	41	38	68	71	76	98	88	116
	#failures	1	6	3	3	4	8	10	3	1	0
	naive	.10	3.46(*)	12.30(***)	5.09(**)	8.07(***)	.95	.02	.29	.00	
	log	.10	3.53	11.44(***)	5.12(*)	7.70(**)	.92	.02	.29	.00	
	cloglog	.10	3.29	10.89(**)	4.38	6.04	.99	.02	.27	-	

5.2 Comparing survival curves

Table 5 is structured in the same way as table 4. The first row gives test statistics for all patents, and these are followed by results by assignee, technology and breadth.

I report the log-rank test because it is a widely used test and enables comparison with previous research (eg Pakes and Simpson 1989 and Deng 2007b) meaningful (Parmar and Machin 1996). I also report Wilcoxon test and Peto-Peto test results in order to add robustness to the log-rank test results (Table 5).

According to the tests, the renewal rates of patents for instruments were significantly different for patents that had the option to be renewed for 17 versus 20 years. There is also weak evidence of differences for patents owned by firms.

Thus, the log-rank type of tests support the results found in the sub-section above. The change in the patent law did not change the renewal behaviour. However, as noted above, the log-rank test may fail when survival rates cross and therefore I also use next the Kolmogorov-Smirnov test.

Table 5: Log-rank tests for a changes in renewal behavior. *** ,**,*= significant at 1% , 5% , 10% level.

	#obs / #failures	**log-rank test**	**wilcoxon**	**peto**
all	5 957/355	.21	.22	.21
firm	3 770/189	2.46	**2.91***	**2.79***
ind.	2 187/166	1.59	1.23	1.46
che	435/15	.82	.58	.60
con	989/67	.37	.42	.39
ele	502/29	.11	.15	.09
ins	577/43	**7.11*****	**7.16*****	**7.44*****
mec	1 928/118	1.30	1.40	1.48
pro	1507/83	2.44	2.46	2.61
very broad	1 380/74	1.45	1.11	1.28
broad	2 477/139	.00	.00	.00
narrow	1 451/103	.64	.16	.29
very narrow	649/39	.75	.26	.49

The null hypothesis in table 6 is for stochastic dominance. I test whether stochastic dominance hold in both direction. First I test whether patents that were not affected by the new law stochastically dominant the others. Then I test whether patents that were affected by the new law stochastically dominate patents that were not. 79 over 81 means that patents not affected by the patent law stochastically dominate patents that were affected. If this test statistic is small, patents with the option to be renewed for 17 years were more valuable than patents with the option to be renewed for 20 years. 81 over 79 means that patents affected by the patent law stochastically dominate patents that were not affected by the patent law. If this test statistic is small it means that patents that had the option to be renewed for 20 years were more valuable. In order to conclude that the patent law increased the private value of patents, the first test statistic (79 over 81) should be big (larger than 1.073, 1.2239 or 1.5174) and the other test statistic (81 over 79) should be small.

There is no evidence that patents with the possibility to be renewed for 20 years were more valuable than patents than had the option to be renewed for 17 years. On the contrary, there is weak evidence that firm patents with the longer statutory limit were less valuable than firm patents with the shorter limit. Moreover, process patents seem, according to the stochastic dominance test, to have become less valuable after the new law came into force.

Table 6: Kolmogorov-Smirnov test for equality of survival function. *** ,**,*= significant at 1% , 5% , 10% level.

		stat
all	79 over 81	.41
	81 over 79	.59
firm	79 over 81	.08
	81 over 79	**1.10***
ind.	79 over 81	.83
	81 over 79	.00
che	79 over 81	.11
	81 over 79	.57
con	79 over 81	.44
	81 over 79	.41
ele	79 over 81	.45
	81 over 79	.35
ins	79 over 81	.33
	81 over 79	.43
mec	79 over 81	.15
	81 over 79	.91
pro	79 over 81	.00
	81 over 79	**2.06*****
very broad	79 over 81	.35
	81 over 79	.23
broad	79 over 81	.51
	81 over 79	.38
narrow	79 over 81	.72
	81 over 79	.36
very narrow	79 over 81	.88
	81 over 79	.00

6 Summary and Conclusion

The statutory limit was extended in Finland from 17 to 20 years in 1980. I use this patent law change as a natural experiment to determine the economic life span of patents. According to Nordhaus (1967) the statutory life of patents should be shorter than the economic life if there is technical development that renders patents obsolete. Hence, if we know the economic life of patents, we can say something about the optimal patent life.

I find, using non-parametric tests, that the renewal rates of patents did not change when the statutory patent limit was changed. This suggests that most patent owners did not find that three extra years of monopoly power increased the private value of their patents. The results show that patent owners knew that their patents would become obsolete before the 17th year, which means that the economic life of patents is no longer than 17 years.

I therefore conclude that the optimal patent life is less than 18 years in Finland.

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A Test of whether renewal rates changed in 1977

Table A1: Test for differences in renewal rates in 1979 and 1981. *** ,**,*= significant at 1% , 5% , 10% level. Parentheses mean that there are significant differences in the renewal curves, but the difference is not according to theory, ie there are more failures in 1981 than in 1979, even though the sample is smaller in 1981.

		7	6	5	4	3	2	1
all	#obs	343	409	516	578	657	779	811
	#failures	64	56	67	42	33	23	4
	stat naive	6.77(***)	**14.45****	**22.87****	2.70	.24	.04	.01
	stat log	6.87(**)	**14.59****	**22.43****	2.67	.24	.04	.01
	stat cloglog	6.55(*)	**13.63****	**20.61****	2.61	.24	.04	.01
firm	#obs	200	243	326	350	370	451	490
	#failures	33	32	34	10	9	10	0
	stat naive	2.25	13.05(***)	**18.60****	2.49	.00	.98	-
	stat log	2.26	13.23(***)	**17.75****	2.46	.00	.98	-
	stat cloglog	2.20	11.34(**)	**15.59****	2.38	.00	.88	-
ind.	#obs	143	166	190	228	287	328	321
	#failures	31	24	33	32	24	13	4
	stat naive	**3.45***	**4.82****	**5.21****	.21	.38	.80	.01
	stat log	3.55	**4.84***	**5.22***	.21	.38	.80	.01
	stat cloglog	3.36	4.72	4.99	.21	.38	.79	.01
che	#obs	20	22	33	44	44	46	56
	#failures	3	2	5	3	0	1	0
	stat naive	.04	2.23	2.08	.56	-	.00	-
	stat log	.04	2.35	2.04	.56	-	.00	-
	stat cloglog	.04	1.77	1.73	.45	-	-	-
con	#obs	68	65	77	100	121	145	133
	#failures	16	8	12	10	7	5	2
	stat naive	.10	31.89(***)	**14.78****	.36	4.55(**)	1.32	.10
	stat log	.10	30.76(***)	**13.71****	.36	4.42	1.31	.10
	stat cloglog	.10	21.99(***)	**12.12****	.35	2.87	1.16	.10

cont.

		7	**6**	**5**	**4**	**3**	**2**	**1**
ele	#obs	34	50	51	54	55	76	80
	#failures	7	12	3	1	3	4	0
	stat naive	3.98(**)	4.62(**)	4.38(**)	1.99	.62	.00	-
	stat log	4.30	4.75(**)	4.15	1.92	.61	.00	-
	stat cloglog	3.74	4.04	3.24	1.64	.60	-	-
ins	#obs	38	42	47	42	51	65	77
	#failures	7	7	6	2	2	1	0
	stat naive	.58	.21	**3.23***	**2.72***	.70	.00	-
	stat log	.58	.21	3.21	2.54	.68	.00	-
	stat cloglog	.57	.21	2.36	1.84	.67	-	-
mec	#obs	108	147	206	216	224	249	256
	#failures	21	17	32	20	13	9	1
	stat naive	1.53	16.90(***)	**24.13*****	3.84(*)	.77	.03	.00
	stat log	1.55	17.87(***)	**23.65*****	3.77	.77	.03	.00
	stat cloglog	1.49	13.97(***)	**18.56*****	3.59	.74	.03	-
pro	#obs	74	82	100	119	156	193	209
	#failures	10	10	9	6	8	3	1
	stat naive	2.30	.20	.05	1.85	4.18	.84	.00
	stat log	2.28	.20	.05	1.83	4.00	.84	.00
	stat cloglog	2.17	.20	.05	1.65	3.81	.72	-
very broad	#obs	68	82	107	120	155	183	182
	#failures	17	9	15	10	7	2	2
	stat naive	.61	.33	.15	.48	**3.58***	.00	.00
	stat log	.61	.33	.15	.48	3.43	.00	.00
	stat cloglog	.60	.33	.15	.47	3.46	.00	.00
		cont.						

		7	6	5	4	3	2	1
broad	#obs	135	166	226	240	263	327	343
	#failures	27	22	29	19	16	14	2
	stat naive	9.42(***)	13.11(***)	**25.06*** **	2.13	1.84	.21	.00
	stat log	9.78(***)	13.53(***)	**24.07*** **	2.10	1.83	.21	.0
	stat cloglog	8.51(**)	11.62(**)	**19.63*** **	2.08	1.67	.20	.00
narrow	#obs	98	123	139	151	171	200	193
	#failures	9	17	17	9	9	5	0
	stat naive	1.11	**2.88***	**8.38*** **	4.88(**)	.05	.41	-
	stat log	1.13	2.86	**8.09*** **	4.72(*)	.05	.41	-
	stat cloglog	1.06	2.79	**6.97***	3.99	.05	.41	-s
very narrow	#obs	42	38	44	67	68	69	93
	#failures	11	8	6	4	1	2	0
	stat naive	.45	8.06(***)	.99	**3.80***	.00	.88	-
	stat log	.45	8.03(**)	.97	3.46	.00	.86	-
	stat cloglog	.45	6.67(**)	.96	3.30	-	.91	-

Table A2: Log-rank test for a change in renewal behavior due to information in 1977. *** ,**,*= significant at 1% , 5% , 10% level.

	#obs / #failures	**log-rank test**	**wilcoxon**	**peto**
all	289/4 093	.83	.77	.74
firm	128/2 430	.42	.33	.38
ind.	1 663/161	**3.43***	2.66	2.66
che	265/14	.07	.18	.10
con	709/60	1.66	1.42	1.41
ele	400/30	2.55	**3.25***	**3.66***
ins	362/25	.83	1.14	.87
mec	1 406/113	.05	.00	.06
pro	933/47	**3.48***	**2.81***	**3.28***
very broad	897/62	.49	.49	.51
broad	1 700/129	.02	.00	.03
narrow	1 075/66	.96	1.05	.94
very narrow	421/32	.05	.09	.16

Table A3: Kolmogorov-Smirnov test for equality of survival function due to a change in statutory limit in year 1977. *** ,**,*= significant at 1% , 5% , 10% level.

		stat
all	76 over 77	.83
	77 over 76	.38
firm	76 over 77	.22
	77 over 76	.46
ind.	76 over 77	**1.08***
	77 over 76	.04
che	76 over 77	.09
	77 over 76	.42
con	76 over 77	**1.14***
	77 over 76	.01
ele	76 over 77	**1.28****
	77 over 76	.25
ins	76 over 77	.00
	77 over 76	.42
mec	76 over 77	.45
	77 over 76	.59
pro	76 over 77	**1.29****
	77 over 76	-.09
very broad	76 over 77	.42
	77 over 76	.00
broad	76 over 77	.49
	77 over 76	.77
narrow	76 over 77	.53
	77 over 76	.09
very narrow	76 over 77	1.47
	77 over 76	.00

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